THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

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GEORGE E. HALE
Mount Wilson Observatory of the Carnegie Institution of Washington

EDWIN B. FROST
Yerkes Observatory of the University of Chicago

HENRY G. GALE
Ryerson Physical Laboratory of the University of Chicago

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† Died, January 30, 1932.

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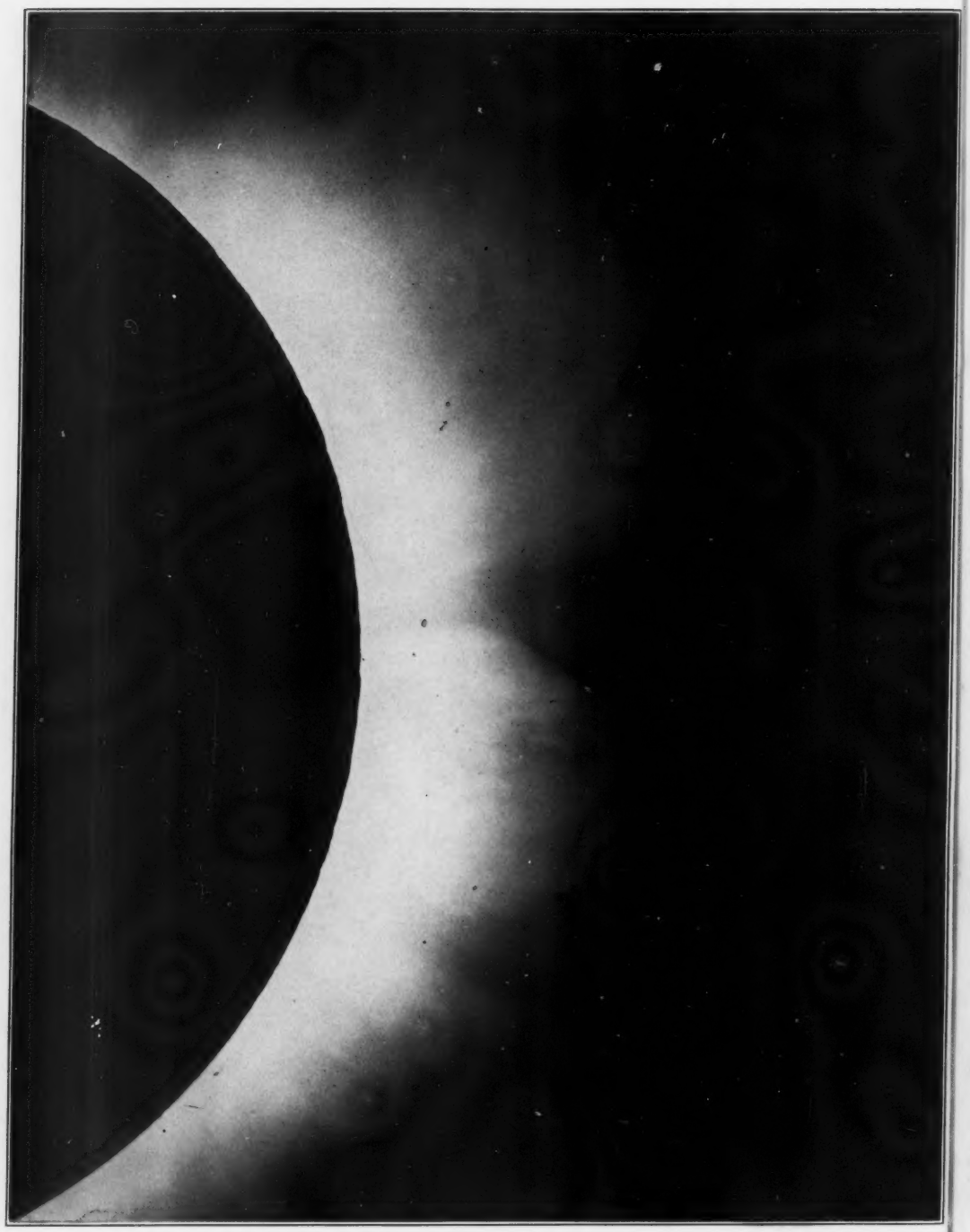

Coronal disturbances to the east of the sun, October 21, 1930. From photograph with 63-foot tower telescope by R. W. Marriott.

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THE ASTROPHYSICAL JOURNAL

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VOLUME LXXV JANUARY 1932 NUMBER 1

THE SPECTRUM OF THE CORONA[1]

By S. A. MITCHELL

ABSTRACT

Excellent weather permitted a most successful expedition at the October, 1930, eclipse.

Spectra were secured by two concave gratings each used without slit. The *chromospheric* photographs are of fine definition between the wave-lengths 3200 and 7800. The *coronal* spectra show a series of rings with good definition and dispersion. The *wave-lengths measured* from the 1930 spectra are 5302.91 and 6374.28, the latter in close coincidence with a line at 6374.29 observed in *neutral oxygen* by J. J. Hopfield. A new line is *discovered* at λ 6776.

The *wave-lengths* are given of nineteen *coronium* lines and their *intensities* observed at different eclipses. Many peculiarities in the intensities are noted.

The *distribution* of coronium at different position angles around the sun was studied in the coronal rings, particularly in the two strong lines 5303 and 6374. The radiation in 6374 was more uniformly distributed in position angle and more concentrated at the photosphere than was found in 5303. In the green line structural details were observed resembling in shape eruptive prominences. Comparisons were made with the structure shown by the direct photographs and by the high-level chromospheric lines. The details exhibited by the green line did not at all resemble those in 6374, and neither line resembled in appearance the prominence structure of the flash spectra or the direct photographs.

These *features of structure and variations in intensities* at former eclipses permit the *grouping* of coronal lines. Only two pairs are recognized with certainty: 3388 and 5303, and 3601 and 4086.

Eclipse photographs, direct and spectroscopic, were compared with prominence plates from the spectroheliograph spread over four days. Throughout this period of time the southeast quadrant of the sun was very active. The *longest coronal streamer*, with associated domes, is found at position angle 150°. Before and after the eclipse, high-level prominences were found at this location but not at eclipse time. At totality the highest prominences were at position angle 115°. They are at the base of the "strawberry dome."

The corona takes its *shape* mainly from the positions of the longest streamers. A study of the shapes of the coronas, particularly those since 1893, reveals the interesting

[1] Published by permission of the superintendent of the United States Naval Observatory.

fact that the *minimum type* of corona, with its long equatorial wings, takes place two years before the sun arrives at minimum activity as revealed by sun-spot and prominence information. Likewise, the *maximum* or circular *type* of corona comes two years earlier than the time of sun-spot or prominence maximum.

Absorption is observed at the base of the coronal rings.

The October, 1930, eclipse on Niuafoou, or "Tin-Can" Island, was dramatic and spectacular; the small isolated, volcanic island far away from home, the difficulty of landing the scientific equipment, the scarcity of fresh water, the interesting natives, all combined to make the trip a memorable one. As the day of the eclipse approached there was the tense anxiety about the weather. Recent expeditions to the Tropics to observe the eclipses of 1926 and 1929 had experienced much trouble from clouds. Weather records kept during the eight weeks preceding the eclipse at Niuafoou had shown that one day in three was clear at the eclipse hour. What fate was in store for us?

On eclipse day conditions before the great event were even worse than usual. Totality was at 8.51 A.M. Two hours preceding a light rain was falling; first contact was lost in heavy clouds. But the clouds began to thin and fifteen minutes before totality they had entirely cleared away. The total phase was observed under nearly perfect conditions. A very slight, almost imperceptible haze covered the sky, but this in no way seemed to affect the photographs. One-half hour after totality clouds again began to gather.

The details of the expedition under the auspices of the United States Naval Observatory are described by Professor Ross W. Marriott.[1] Four times previously I had been a member of Naval Observatory eclipse expeditions: in 1900, 1901, 1905, and 1918.

In 1930, as always before at eclipses, my work was spectroscopic. My record as an eclipse observer is probably unique. I have observed eight solar eclipses, and yet neither the Leander McCormick Observatory nor I personally own a single piece of eclipse apparatus; at each eclipse everything must be borrowed. At Niuafoou I had two spectrographs, each consisting of a concave grating and used without slit.

All the equipment belongs to the Naval Observatory with the exception of one grating of 4-inch aperture and 14,438 lines per inch,

[1] *Popular Astronomy*, **39**, 241, 1930.

kindly loaned to me by Professor F. A. Saunders of Harvard University. This grating has been with me on six occasions: in 1905, 1918, 1923, 1925, 1927, and 1930. Photographs of the flash spectrum were obtained in all but two of the eclipses, in 1923 in Southern California and 1927 in Norway, when heavy clouds were experienced. The photographs at the Oregon eclipse of 1918 were through thin clouds and hence the spectra are feeble. The spectrum of the chromosphere was photographed with clear skies in 1905 and 1925, and now again in 1930. The results obtained in 1905 and 1925 are published in *Astrophysical Journal*, **71**, 1, 1930 and **72**, 146, 1930.

The other concave grating used in 1930 is of 6-inch aperture and 15,000 lines per inch. Both gratings are of 10-foot radius of curvature. This grating had previously been with me at the eclipses of 1923 and 1927, but owing to clouds no photographs were obtained. The 6-inch grating has ruled lines 3 inches in length while those of the 4-inch grating are only 2 inches long. The 6-inch grating has therefore a light gathering surface over double that of the 4-inch. Both are Rowland gratings, both were used in the first order—and it need hardly be added, the more brilliant first order was utilized. It was long ago recognized by L. E. Jewell that the Saunders 4-inch grating is a remarkably perfect one—in fact, its definition is better than that of the Naval Observatory 6-inch grating. However, the 1930 spectra showed, as was expected, the 6-inch spectra to be of greater strength than those taken with the other grating.

Accompanied by Mrs. Mitchell and by my personal assistant, Mr. Herbert P. Fales of Pasadena, we sailed from San Francisco on August 21. Mr. Fales and I arrived at Niuafoou on board U.S.S. "Tanager" on September 10, six weeks before the eclipse. In the erection of the spectrographs I had the assistance of Mr. Fales and chief machinist's mate Coffey. A site was selected close to the concrete base supporting the Swarthmore 63-foot tower telescope and to the north of the tower so that it would act as a break for the southeast trade winds. It was difficult to secure stability in the shallow soil covering the lava rocks. Great care was necessary to make the supports rigid so that the instruments would not be jarred in making the exposures at eclipse time.

The two spectrographs were arranged side by side. A "transit of

Venus" coelostat was used for each, and the beam of sunlight was reflected horizontally on the grating. An extra mirror accompanied the coelostats, and this was used for purposes of adjustment. The two mirrors used on the day of the eclipse had been freshly silvered immediately before the equipment left the Naval Observatory. They were kept sealed tightly until the morning of the eclipse when each was found to be in excellent condition.

On account of the sharp curvature of the field of good focus of the gratings, a radius of 30 inches, glass plates could not be used. The films coated on celluloid base were $1\frac{1}{4}$ inches wide. One of the spectrograph boxes took a film 14 inches in length, the other, 12 inches. Each spectrograph had two plate-holders. For the 14-inch there were six films in each flat plate-holder, while the plate-holders for the other grating carried four films each. It was decided to use the 4-inch grating in the box of seasoned pine with films 14 inches in length and to utilize this at the violet end of the spectrum, while on account of its greater light-gathering power, the 6-inch grating in the mahogany box was used at the red end of the spectrum. The dispersion of each grating is approximately 10.9 A per millimeter, and hence the 14-inch film covered about 3800 A and the 12-inch an extent of 3260 A. The region from λ 4650 to λ 6800 was photographed by both spectrographs.

Through the kind offices of Dr. C. E. K. Mees all the films were coated by the Eastman Kodak Company. For the 14-inch spectra, used on the violet side of λ 6800, "Commercial Panchromatic" films were employed. For the 6-inch grating two films were used, one overlapping the other, the "Commercial Panchromatic" to the violet of λ 6800 and "Panchromatic K" (stained with kryptocyanine) to the red of this wave-length. The films for the violet end were on a heavier base than those for the red end. With three of the films of the six-inch grating Wratten K 1 filters were used in the plate-holder in contact with the "Panchromatic K" films in order to absorb the ultra-violet of the second-order spectrum. On account of the tropical conditions, with lava dust blowing everywhere and no facilities for rapid drying, no attempts were made to hypersensitize the films.

METHOD OF SECURING FOCUS

The writer has always made it a habit to be at the eclipse site a month or six weeks in advance so that there may be plenty of time, without too much rush and excitement immediately preceding the eclipse.

In *Handbuch der Astrophysik*, **4**, 275, 1929, the difficulties are stressed of securing eclipse photographs of perfect focus. The writer has always worked with gratings without slit. For securing focus a collimator has been utilized consisting of a slit in the common focus of two parabolic speculum metal mirrors. When electric power is available, it has always been found easier and more efficient to use the electric arc as the source of light rather than the sun. This method was followed in the eclipses of 1923, 1925, and 1927. At Niuafoou there was no electric power and hence there was nothing to do but use the tropical sun as the source of light for adjusting purposes. The difficulties underlying this process are at once evident. In the optical train while adjusting, there are four mirror surfaces: the coelostat of silver on glass, the two metal mirrors of the collimator, and the grating itself. In the adjustment the slit becomes the source of light, and hence it is of minor importance if the coelostat mirror is not plane or if the slit is not in the exact focus of the first collimator mirror which forms the image of the sun on the slit.

Excellent focus requires, among other things, that on the eclipse day the coelostat mirror be plane and not warped by the direct rays of the sun. (The mirror was screened from the sunlight until a few minutes before totality.) No matter how carefully the focus is determined, the great fear is always present lest the grating alter its focal length, owing to changes of temperature between the time of adjustment and the time of the eclipse. This requires in addition that the wooden boxes and plate-holders should not expand or contract enough to alter the focus. And all these nice adjustments had to be taken care of on a tropical island, with clouds always interfering with work, with the dark room during the daytime with temperatures that felt like inferno, and with no ice and no running water for development. The trials and tribulations of an eclipse astronomer are many, especially when working with apparatus which is

temporary and which must always be borrowed! There is only one philosophy of life, namely, to be an optimist and to do the best one can.

The two mirrors of the collimator were adjusted for parallel light in the method always followed by the writer, by means of a visual telescope of about 6-foot focal length focused on the stars. With the collimator placed in the beam of light between coelostat mirror and grating, the focus was first determined visually with as great care as possible. For improving the focus, about a hundred and fifty focus plates were taken. The extreme range of focus in the last hundred of these films was merely $\frac{1}{2}$ mm, together with slight changes in the inclination of the photographic film to the normal to the grating.

During the weeks of preparation the 3-inch telescope (used for focusing the collimator) was frequently brought out at night to show the stars to the three white men residing on the island, to the visiting Europeans who came to audit the books of the two trading companies, and to the native Polynesians. What impressed me on almost every occasion was the poor seeing—in fact, very much poorer than is ever found at home with the 5-inch finder attached to the 26-inch McCormick refractor. Perfect definition for the flash spectrum without slit requires perfect seeing, otherwise the spectral lines instead of being sharp and cleanly-cut will be hazy and ill defined on their edges.

As is well known, the concave grating gives a "normal" spectrum if the grating and photographic plate are each perpendicular to the lines joining their centers. In that which follows an example will be given to show how nearly the 1930 spectra were normal.

THE ECLIPSE SPECTRA

At the time of the eclipse the two grating spectrographs were handled by:

Four-Inch	Six-Inch
S. A. Mitchell	Lieut. Laurence Bennett, U.S.N.
Herbert P. Fales	C.M.M. John L. Coffey

The first named in each case made the exposures by opening and closing a flap shutter; the second assisted by shifting and changing the plate-holders. The 6-inch grating had an "all-Navy team." I

explained to the Captain of the U.S.S. "Tanager" that the two longer exposures during totality would give him an opportunity to get a good look at the corona. Captain Bennett's reply was characteristic of this efficient officer: "I am here to do a good job on making those exposures, and whether I see the corona or not is of little importance." With such a spirit among my co-workers it need hardly be added that at eclipse time everything went off without a single hitch.

The photographic work of the two expeditions, American and New Zealand, consisted of direct photography and spectrographic

TABLE I

Four-Inch				Six-Inch			
Film No.	Exposures		Duration in Seconds	Film No.	Exposures		Duration in Seconds
	Began	Ended			Began	Ended	
1	"Go"	3	3	1	"Go"	3	3
2	5	10	5	2	5	10	5
3	12	22	10	3	12	22	10
4	24	44	20	4	24	44	20
5	54	69	15	5	60	81	21
6	71	81	10	6	83	88	5
7	83	88	5	7	90	"Stop"	3
8	90	"Stop"	3	8	Quick		.....
9	Quick		.....				
10	Quick		.....				

work. I was to give the signal "Go" for the spectrographs, while Professor Marriott, watching the image made by the 63-foot tower camera, was to give the signal for beginning the direct photography of the corona when the last Baily bead had disappeared. My signal naturally would come before the other. I was to yell "Stop!" I had an old-fashioned pair of binoculars. In front of the right lens I had a replica grating of 15,000 lines per inch and a dark glass over the left lens. These signals for beginning and ending operations depended on my ability to see the flash spectrum.

The observation programs for the two gratings were as shown in Table I.

Ten films were taken with the 4-inch and eight with the 6-inch grating. Plate-holders were changed in each case after the fourth

film, the programs for the two spectrographs being the same up to the change of plate-holders. The program was rigorously followed. The "count" was given in a loud voice by the chief quartermaster's mate Bell, a metronome being used which was carefully adjusted before the eclipse to beat seconds and again checked immediately after totality. The duration of totality calculated by the New Zealand expedition was 95 seconds, and hence the exposure for the second flash was begun with "90" by the count. (As events showed the duration was shorter than expected.) Immediately after the second

TABLE II

	Second Contact	Third Contact
Computed time, Oct. 21	$20^h50^m59^s6$	$20^h52^m32^s8$
Observed time, Oct. 21	21 51 03.05	20 52 36.92
Difference, moon late	3^s45	4^s12

flash the plate-holders were shifted and exposures were made as rapidly as possible, two films being secured with the 4-inch grating and one with the 6-inch.

Mrs. Mitchell and other ladies and extra assistants arrived the day before the eclipse aboard the two naval vessels "Tanager" and "Ontario." At eclipse time my wife had two jobs. In her left hand she held a telegraph key which gave my signal of "Go" and "Stop" to the New Zealand party. In her right hand she held another key to record these two signals on the chronograph.

Captain J. F. Hellweg, U.S.N., superintendent of the Naval Observatory, has kindly sent me the times of contacts after correcting the moon's positions for changes in x and y (see Table II).

It will be noticed that the final revision of the computed duration of totality is 93.2 seconds and that both second and third contacts occurred later than was expected. My notes made at the time were, "My signal of 'Go' was one-half second ahead of that given by Mr. Bevan P. Sharpless, and this in turn was ahead of Professor Marriott's."

In the several eclipses observed I have never before had as gratifying a view of the flash spectrum, both at the beginning and at the

PLATE II

The brighter portions of the corona, October 21, 1930, showing same region as Plate I; taken 6–11 seconds after the beginning of totality by R. W. Marriott.

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ending of totality. One handicap in photographing the flash spectrum is that there are so few opportunities to rehearse in one's lifetime. Apparently my reaction time (like that of everybody else who has photographed the flash spectrum) is not instantaneous; the first flash does not record the chromospheric lines of *lowest* levels. At the end of totality I hung on as long as possible before yelling "Stop!" The second flash that I myself closed with this signal shows almost perfect timing. A study of the photograph of the first flash shows that my signal "Go" was late by approximately 0.38 seconds. Assuming this as the correction to the differences above, it will be seen that second contact took place 3.0 seconds later than the computed value and third contact 4.1 seconds later, the actual duration being 1.1 seconds greater than the calculated value. On account of the rough character of the moon's edge one has to raise anew the time-honored question of what one means by the "beginning" and "ending" of a total eclipse.

On the night immediately following the eclipse Professor Marriott started on the development of the coronal photographs. On the following night the dark room was given over to my exclusive use. As soon as it had cooled somewhat I started, and with the help of ice brought for the purpose I was able to keep the developing, fixing, and washing baths in fairly satisfactory condition. At daylight the films were hung up to dry.

When all the photographic plates, direct corona and spectrographic, were developed, the eclipse camp was a cheery place. We had been fighting against tremendous odds but we had won out. I have never seen more exquisite detail than is found on the coronal photographs taken under the direction of Professor Marriott. My own spectra left little to be desired, with good focus from λ 3200 to λ 7800 and with the region from 4650 to 6800 in duplicate.

THE SPECTRUM OF CORONIUM

The discussion of the 1930 spectrum of the chromosphere must needs await a future publication. The green line of "coronium" was discovered in 1869. Since that date the time spent in photographing the coronal spectrum has amounted to a grand total of about one hour, an average of one minute per year. Spectrographs of all vari-

eties and conditions, with and without slit, have been utilized. On account of the paucity of light the dispersion has usually been small. After a half-century of observation Campbell and Moore[1] summarized all the information known up to and including the eclipse of 1918. Forty lines observed during totality by various authorities were listed as possibly coronal in origin. It was suspected by the Lick observers that many of the lines belonged to the high chromosphere rather than to the corona. More than half the forty lines are now known (see below) to belong to the chromosphere. Coronal wave-lengths even yet are known with little accuracy, some of the values being uncertain even to the nearest angstrom.

Little of scientific value was expected in advance from the 1930 photographs of the coronal spectrum. How thrilling it was to find a complete ring belonging to coronium never before known, and to see in the slitless images of the strongest lines at 5303 and 6374 structural details resembling eruptive prominences! The wave-length for the new line derived on Niuafoou from a millimeter scale and low-power eyepiece was λ 6777. In order not to appear to claim too great accuracy, the final figure was rounded off to zero, and the value announced by radio was λ 6770. The measured value (see below) is λ 6776. This line is found on three separate photographs, two with the 6-inch and one with the 4-inch grating.

NORMAL SPECTRUM

To show the ease with which wave-lengths are reduced from the measures, an example is given for film No. 6 of the 6-inch grating measured to derive the wave-lengths of the coronium lines. This film, taken just before the second flash, shows the high-level chromospheric lines, and as a Wratten filter was not used, there are lines of both first and second orders. In Table III, in the first column, is the wave-length from the *Revised Rowland;* in the second column, I and II signify first and second order—if second order, the Rowland wave-length, is multiplied by 2. In the fourth column is the chromospheric intensity taken from *Astrophysical Journal*, **71**, 1, 1930, and in the last is found the difference between the measured and Rowland wave-lengths. The film was measured by the writer in the Rep-

[1] *Lick Observatory Bulletin*, No. 318, 1918.

sold machine in which the measures on the spectral lines are referred immediately to a millimeter scale. The scale of this film (10.92993 A per millimeter) was derived from the measures, using the interval from the line D2 to λ 3383 in the second order. The constant 5576.11 was set up on the multiplying machine. The measured positions in millimeters multiplied by the scale value and added to the constant gave immediately the measured wave-lengths. The foregoing values come from one measure of the plate consisting of two settings on the spectral line and one on the millimeter scale.

TABLE III

MEASUREMENT AND REDUCTION OF NORMAL SPECTRUM

Rowland Wave-Length	Order	Equivalent Wave-Length	Intensity Chromosphere	Difference $M-R$
5889.98	I	5889.98	25	−0.10
5895.94	I	5895.94	20	− .07
6141.73	I	6141.73	20	− .08
3329.44	II	6658.88	18	+ .06
6678.15	I	6678.15	20	− .11
3341.88	II	6683.76	25	+ .10
3348.98	II	6697.96	20	+ .15
3349.45	II	6698.90	35	− .02
3361.23	II	6722.46	25	− .05
3368.06	II	6736.12	18	+ .05
3372.81	II	6745.62	30	− .01
3383.84	II	6767.68	25	− .10
3387.85	II	6775.70	18	+0.14

It will be seen that the range of wave-lengths is nearly 900 A. The differences $M-R$ are made up of a number of sources of errors, chief among which are: errors of measurement which are large on account of the wide range in intensities of lines measured and imperfect definition; scale inaccurately determined; spectrum not normal, etc.

CORONIUM WAVE-LENGTHS IN 1930

Although the coronal lines were taken without slit, the edges toward the photosphere were sufficiently sharp and clear cut to make measures of value. Eight films were measured for the green line 5303, six for 6374, and two of 6776. On account of the greater intensity of images given by the 6-inch grating, already referred to, the only measures made from the 4-inch spectra were on the green line.

The results of the measures are given below. The coronium lines are referred to the high-level chromospheric lines. On some of the films the eastern edge only of the coronium lines could be measured accurately, on others the western edge only, while on some of the longer exposures both edges were measured. The weight given in Table IV is a combination of the definition and the number of edges measured. The films on a celluloid base are very sensitive to changes of temperature. All spectra were assumed to be normal, and the

TABLE IV

WAVE-LENGTHS MEASURED

Grating in Inches	Film No.	Wave-Length	Wt.	Wave-Length	Wt.	Wave-Length	Wt.
6.....	2	5302.79	1	6374.09	1	.....	.....
6.....	3	5303.04	2	6374.15	2	.....	.....
6.....	4	5302.80	2	6374.22	2	.....	.....
6.....	5	.....	.....	6374.28	2	6775.85	2
6.....	6	5302.98	2	6374.51	2	6776.00	1
6.....	7	5302.98	2	6374.39	1	.....	.....
4.....	5	5302.96	2	.....	.....	.....	.....
4.....	6	5302.86	2	.....	.....	.....	.....
4.....	9	5302.63	1	.....	.....	.....	.....
		5302.91		**6374.28**		**6775.90**	

scale value was determined separately for each measurement of the film. The wave-lengths in the table give the mean of the individual measures. No correction was applied for the rotation of the corona (i.e., for the differential rotation of the corona with respect to the chromosphere). No systematic difference in wave-lengths could be detected between measures on the eastern and western edges of the corona.

The paucity of information about coronal wave-lengths is illustrated by the fact that it was not until 1898 that the green line was found to be at λ 5303 and was not identical with the 1474 K line now known to belong to Fe^{+} at λ 5317. Heretofore the most accurate measures of the green line result from the 1918 eclipse, by Campbell and Moore,[1] and by Adams, St. John, and Miss Ware.[2] Uncorrected for rotation (0.035 A), and corrected (assuming the corona rotates

[1] *Ibid.* [2] *Publications of the Astronomical Society of the Pacific*, **30**, 251, 1918.

at the same rate as the photosphere), the values in international angstroms are as shown in Table V.

The 1930 measures give **5302.91,** in good agreement with the mean of the 1918 results.

At the April, 1930, eclipse Moore and Menzel[1] with three-prism slit spectrograph give the measured value of the green line referred to neighboring chromospheric lines as 5303.9 (I.A.). By applying a large correction of −0.9 A, which seems none too accurately determined, they derive a reduced wave-length of 5303.0.

TABLE V

	Uncorrected	Corrected
Campbell and Moore	5302.83	5302.80
Adams, St. John, and Ware	5303.02	5303.06
Difference		0.26
Mean		**5302.93**

None of the measures of the red line, first discovered at the 1914 eclipse, professes to have a high precision. The 1930 value is **6374.28.**

The mean for the new line is 6775.90. The last digit means nothing, and that in tenths of angstroms means little. We shall therefore assume the wave-length to be **6776.**

WAVE-LENGTHS AND INTENSITIES

In his book *Eclipses of the Sun* (2d ed., 1924), and in *Handbuch der Astrophysik,* **4,** 315–353, 1929, the writer has called attention to the pitifully small amount of definite information known up to the present about the corona, the reason being the paucity of light available and the few opportunities for research. It is always a great temptation, however, for a scientist to draw conclusions from the observational facts even though, as in the case of the coronal spectrum, the observations themselves are very meager.

As is well known, the spectrum of the corona has three separate characteristics: first, the bright-line spectrum of "coronium" existing only in the inner corona and extending on the average to about

[1] *Ibid.,* **42,** 182, 1930.

5′ or 200,000 km from the sun's edge; second, the continuous spectrum of the middle corona; and, third, the Fraunhofer lines showing feebly in the outer corona.

In the *Revised Rowland Tables*, page 226, 1928, is given a list of bright lines attributed to the corona by Campbell and Moore[1] but revised to include[2] the 1926 eclipse. In *Zeitschrift für Astrophysik*, **2**, 106, 1931, W. Grotrian gives the results of the Potsdam expedition to Sumatra of May 9, 1929. In Table VI the 1930 eclipse is also included. After eliminating the lines due to the high chromosphere, there are nineteen lines which are now believed to be truly coronal in origin, although a line or two may still be suspicious. The first column gives the wave-lengths in international units. Those at the top of the table, given to two places of decimals, are from the 1926 eclipse by Davidson and Stratton. The values of 5302.91 and 6374.28 are from the 1930 spectra. The line at λ 6704 was discovered at the 1929 eclipse and verified by the 1926 eclipse photographs. The intensities given in the remaining columns are estimates where the strongest lines, 3388 in the violet and 5303 in the green, are usually assumed to be of intensity 20. The intensities given in the Table are those assigned by the observers except for the 1918 eclipse where Moore and Campbell's estimates are each multiplied by the factor 2 so that the line 5303 may have an intensity 20. For the 1922 eclipse the intensities have been furnished by letter through the kindness of Moore. In the second column an average intensity is assigned from the mean of all the eclipses.

The intensities of the coronal lines in the table must be considered to be on a *relative* scale and not *absolute* for the reason that 5303 varies from eclipse to eclipse and is not constant as was assumed in forming the tabular values.

Before taking up the striking differences in the intensities from eclipse to eclipse shown by the table, one must consider the factors upon which the coronal intensities depend. They may be grouped under four heads: (1) color sensitivity of the photographic plate, (2) the dispersion, (3) prism or grating, and (4) slit or slitless. The improvements in plates in recent years, making them more sensitive at

[1] *Lick Observatory Bulletin*, **10**, 8, 1918.

[2] Davidson and Stratton, *Memoirs of the Royal Astronomical Society*, **64**, 105, 1927.

the red end, are mainly responsible for the discovery of the lines in the red. Prisms of glass absorb at the violet end of the spectrum; gratings (of speculum metal) and the silver-on-glass reflectors absorb in the ultra-violet. Increase of dispersion spreads the monochomatic images farther apart and weakens the continuous spectrum, with the result that the emission lines by contrast are easier to see on the photographs taken with higher dispersion.

At the 1930 eclipse on Niuafoou there was a striking difference between the coronal spectra taken with the concave gratings and

TABLE VI

WAVE-LENGTHS AND INTENSITIES OF CORONIUM

WAVE-LENGTH I.A.	MEAN INTENSITY	HILLS AND NEWALL, 1896	FOWLER, SHACKLETON, AND LOCKYER, 1898	DYSON MEAN 1900–1901–1905	LEWIS, 1908	MOORE AND CAMPBELL, 1918	MOORE, 1922	DAVIDSON AND STRATTON, 1926	GROTRIAN, 1929	MITCHELL		
										1905	1925	1930
3328.....	8	.....	.....	.....	.....	.....	.....	.....	8	....	....	....
3387.96...	20	.....	.....	12	30	.....	.....	20	20	20	20	20
3454.13...	8	.....	.....	9	8	.....	.....	5	8	10	5	6
3600.97...	10	.....	.....	.....	15	10	6	9	12	....	15	15
3642.87...	3	.....	.....	2	5	4	.....	3	.....	4	?	4
3800.77...	3	3	3	3	3	2	.....	4	1	3	3?	3
3986.88...	8	5	5	3	4	2	4	10	5	8	4	8
4086.29...	6	.....	.....	.....	6	2	2	8	6	....	4	6
4231.4....	8	10	5	5	8	6	8	10	8	6	6	6
4311.....	2	.....	.....	2	1	.....	.....	2	1	....	....	....
4359.....	4	3	3	4	.....	.....	.....	4	1	2	....	2
4567.....	4	8	3	6	.....	2	.....	6	3	....	....	....
4586.....	2	.....	1	4	.....	.....	.....	4	.....	....	....	....
5117.....	2	.....	.....	2	1	.....	.....	2	5	....	....	....
5302.91...	20	8	10	20	10	20	20	20	20	20	20	20
5536.....	1	.....	.....	2	.....	.....	.....	2	.....	....	....	....
6374.28...	12	.....	.....	.....	.....	.....	.....	5	6	....	15	15
6704.....	2	.....	.....	.....	.....	.....	.....	.....	4	....	....	....
6776.....	8	.....	.....	.....	.....	.....	.....	.....	.....	....	....	8

with the prismatic camera of Dr. C. E. Adams of the New Zealand expedition. The prismatic camera gave a very brilliant spectrum—in fact, more brilliant than that of either concave grating. Both forms of spectrographs were without slits. The dispersion of the gratings, however, was ten times the average dispersion of the prismatic spectrum. Many coronal rings were seen on the grating photographs, the lines 5303 and 6374 being well visible even on the brief exposure for the second flash. On the prismatic spectra, on the contrary, the only coronal line visible on any of the photographs was 5303, and even this line was seen with great difficulty.

Similarly in 1925, the line 6374 was seen on the photographs of the

second flash taken with the 4-inch grating; and yet with a prismatic camera (kindly loaned by the Lick Observatory), with a dispersion about one-seventh of that of the grating, the only coronal line visible on a long exposure given throughout the whole of totality was again the 5303 line, which had very little contrast compared with the continuous spectrum. It is readily seen, therefore, that the dispersion employed has a very important bearing on the intensities, and hence any conclusions drawn from variations in intensities between the lines of one eclipse and another have very little meaning unless the instrumental conditions are fairly constant.

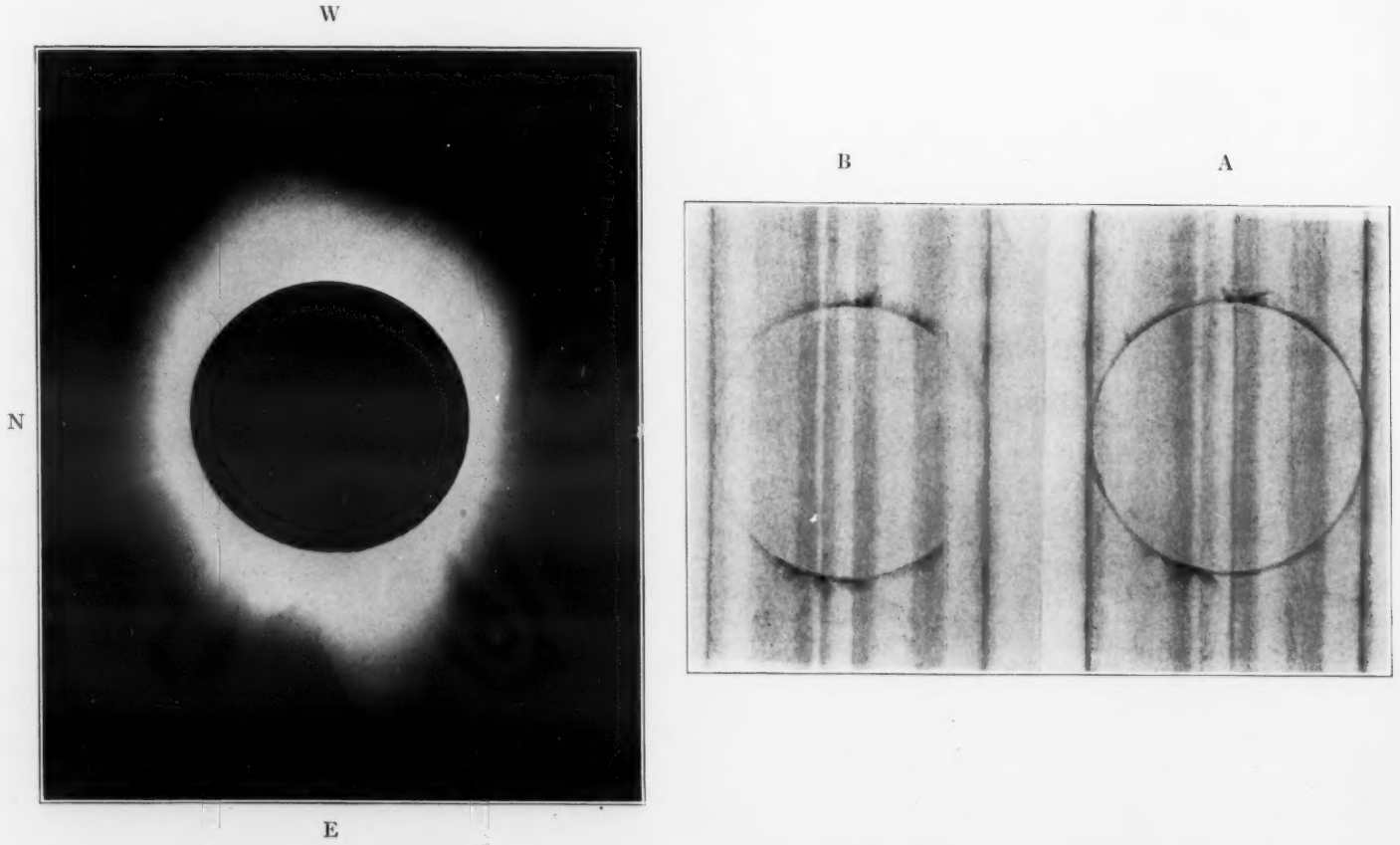
The specially interesting features of the coronal spectra of 1930 are the large dispersion and absence of slit. On the photographs the image of the sun is 14.5 mm in diameter and the dispersion 10.9 A per millimeter. All the coronal rings show much interesting detailed structure, but this is especially true for the strong 5303 and 6374 rings. On Plate III the vertical line coincides approximately with the axis of rotation of the sun. One can see at a glance that if a slit had been used in 1930 passing radially through the center of the sun, the intensity of 5303 (or 6374) would have depended on the position angle of the slit. If placed near the solar axis, the coronal lines would have been feeble; while if it had happened to pass over a more brilliant portion (which could not have been told in advance), the intensity would have been much greater.

Hence for discussing the distribution of coronium about the sun, slitless spectra (if obtained with large dispersion and good definition) are vastly superior to those taken with a slit.

With these instrumental sources of variations in intensities clearly in mind, let us look at the estimates of intensities in Table VI. There are several striking peculiarities. Many of these, and others, have already been noted by Campbell and Moore.[1] The most remarkable involves the line at λ 3601. It was not observed by anyone until the eclipse of 1908, in spite of the fact that it is one of the strongest lines of the coronal spectrum and the quartz spectrographs were adequate to secure it. The photographs by Mitchell at the three eclipses of 1905, 1925, and 1930 were taken with the same spectrograph, the 4-inch concave grating without slit. The plates of the three eclipses

[1] *Lick Observatory Bulletin*, No. 318, 918.

PLATE III



Left: Photograph of corona by R. W. Marriott with 15-foot Swarthmore camera. *Right:* Two drawings by Emma T. R. Williams from spectra by concave grating; showing (*A*) the ring for λ 6374 and (*B*) the green ring for 5303 of "coronium."

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have about the same sensitivity in the violet. No trace of λ 3601 is found in 1905 although 3388 and 3454 farther to the violet are strong lines. By way of contrast, in 1925 and 1930 the line 3601 was very strong. (Other peculiarities of this line will be referred to later.) Likewise, λ 4086 was not observed before 1908. At the 1929 eclipse Grotrian[1] reports three lines missing, λλ 3643, 4586, and 5536. The last line of the three is the weakest of the whole coronium spectrum; it is, moreover, near a Fe^{+} line in the chromosphere of λ 5534.85 and intensity 15 in the flash spectrum. Davidson and Stratton ascribe this line to the corona. The first of the three lines, at λ 3643, is on the average a fairly strong line. Mitchell could not be sure of it from his 1925 spectra, however, though it was well visible in 1905 and 1930.

One's first thought presented for an explanation of these peculiarities is that the intensities vary, and, having settled this to one's satisfaction, the next thing is to try and connect the variation with the sun-spot cycle. There we strike a snag. The years 1900 and 1901 had coronas of minimum type while the 1905 eclipse was of maximum type, and yet λ 3601 was invisible in all three years and, moreover, it has been a strong line in every eclipse without exception since 1908.

Before pursuing this subject farther it will be well to compare the distribution of light in the strong coronal rings 5303 and 6374 obtained by the concave gratings.

THE DISTRIBUTION OF CORONIUM

This is the first time in the history of eclipses that so much of detailed structure has been obtained in the spectral lines of the corona. This structure was made possible by the fine definition with the slitless images of high dispersion, but the chief cause was found in the great activity of the sun. A comparison of all the 1930 grating spectrograms, but more particularly a study of the H and K lines, reveals the interesting fact that at the time of the eclipse the sun was indeed in a condition of great activity, prominences being found completely encircling the sun. This activity is confirmed by the direct photographs.

With the 63-foot Swarthmore tower telescope Professor Ross W.

[1] *Loc. cit.*

Marriott made three exposures of short duration, as shown in Table VII.

The superb definition of these photographs shows not only the prominences but the structure of the inner corona in great beauty. On account of the fact that the eclipse site was not on the central line of totality, the moon's edge was closer to the southern than to the northern limb of the sun, with the result that the prominences, both on the spectra and on the direct photographs, show more readily in the southern hemisphere than in the northern.

Through the kindness of Director Royds of Kodaikanal and of Dr. S. B. Nicholson of Mount Wilson Observatory, prominence

TABLE VII

Plate No.	Beginning and Ending after Signal "Go" (in Seconds)	Exposure in Seconds
2	6–11	5
4	45–46	1
7	86–89	3

plates have been sent for comparison with the eclipse photographs. The spectroheliograms were taken on the following dates and Greenwich civil times, the first plate being from Kodaikanal, the other four from Mount Wilson: October 20, 2^h46^m; October 20, 19^h22^m; October 21, 17^h32^m; October 22, 19^h58^m; and October 23, 18^h24^m. A cloudy spell at Kodaikanal prevented photographs between October 20 and 26. The definition of the Mount Wilson plates is only fair. Totality took place on October 21 at 20^h51^m G.C.T.

A comparison of all the photographs, the spectroheliograms with the eclipse plates both direct and spectrographic, shows that the sun was very active not only at eclipse time but throughout the whole period covered by the plates of nearly four days. At the time of totality there was a prominence almost exactly at the south point of the sun extending to a height of 25,000 km. At this time the axis of rotation passed 26° to the west of the south point. The photographs, direct and spectrographic, show prominences even at the north and south poles of the sun's axis.

Marriott's photographs and the eclipse spectra exhibit that the

whole southeast quadrant was a tremendously stormy region on the sun. The center of the longest streamers of the whole corona was situated 30° to the east of the south point of the sun, or at position angle 150°. Intertwining the coronal streamers is a beautiful series of coronal domes. At totality, at the base of the long streamers and domes is an extended group of prominences centered at 150° of position angle. These prominences, though apparently very active as shown by the eclipse photographs, did not reach the greatest heights on the sun. These greatest heights were actually attained by prominences also in the southeast quadrant but at 115° of position angle. This is the location of the conspicuous feature called the "strawberry dome," with its magnificent series of arches and with its delicate intertwined structure of filamentous details. In Plate IVB is a drawing made by Emma T. R. Williams from the region of the sun where the strawberry-shaped disturbance is found in the direct photographs of the corona. The drawing is from Marriott's photograph No. 2, a portion of which is reproduced in Plate II, exposed from 6 to 11 seconds after the signal "Go." In Plate IVA are drawings of the same solar region made from eclipse spectra as shown by the K line of Ca^+ and the $H\alpha$ of hydrogen.

On the Kodaikanal spectroheliogram taken on October 20, at position angle 150° there is found an eruptive prominence extending to a height of 50,000 km. On the same date, October 20, but about sixteen hours later, the Mount Wilson spectroheliogram does not show a prominence at this position angle nor yet the following day, October 21, at 17^h32^m G.C.T., three hours and nineteen minutes before totality occurred. However, the day following the eclipse, October 22, and again on October 23 at the same position angle of 150°, eruptive prominences are readily visible, those on the latter date extending to a distance of 90,000 km. It is interesting to find the solar activity persisting at 150° position angle through a period of four days. From the two Mount Wilson photographs (which unfortunately were only of fair quality) on October 20 and 21 one might think that the activity had died down but had flared up again later. However, the photographs taken at the eclipse show the sun very active at position angle 150° but without high prominences (see Pl. II). Hence we find that the most active region of the whole sun,

with disturbances extending over a period of four days, was the location of the longest streamers in the corona.

The coronal streamers in the northwest quadrant of the sun did not reach as great length as those to the southeast. The center of the greatest prominence group at eclipse time in the northwest is at position angle 300°, and this coincides with the center of the coronal streamers to the northwest. In Plate IVC is given a drawing from Marriott's photograph No. 7, of three seconds' duration just before the end of totality, the detail in 5303 resembling the coconut trees which grow in such profusion on Niuafoou Island. The spectroheliograms show the sun very much less active in this quadrant than it is in the southeast quadrant. None of the spectroheliograms shows the high-level prominence group so well visible on Marriott's photographs as given in Plate IVC.

For many long years eclipse observers have called attention to the connection between coronal streamers and prominences. This dependence of streamers on prominence activity is abundantly verified in 1930, but this eclipse demonstrates the fact that the *longest* coronal streamers, on which the shape of the corona more or less depends, are not necessarily those connected with the prominences which at the time of the eclipse are of the *greatest* height. It has been evident to all investigators that the coronal streamers and hence the shape of the corona depend on the solar activity manifested by the numbers of spots and prominences increasing and decreasing together in the sun-spot cycle, but it must not be assumed that the prominences which are rendered most readily visible by their great heights are necessarily the centers of the most active solar disturbances.

An examination of all the 1930 grating spectra shows that the continuous spectrum traversing the lengths of all of the photographs is in origin both chromospheric and coronal. Moreover, it is not the chromosphere of highest levels, exhibited by the prominences, that gives the strongest continuous spectrum. This is shown very clearly from the drawings reproduced in Plate IVA: the high-level prominences in the light of K and *Hα* are associated with little continuous spectrum. The continuous spectrum of the chromosphere is associated with low-level rather than with high-level activity.

All observers who have discussed slitless coronal spectra have

called attention to the distribution of light in the green ring at λ 5303. V. M. Slipher states:

> The coronium ring is faint or absent along the sections of the sun's limb occupied by the bristling streamers typical of the polar regions. The spectrogram, compared with direct photographs, shows that the coronium substance was relatively abundant generally in those regions of the sun's limb from which flowed the great extensions of the corona.[1]

Davidson and Stratton make the following remarks (together with others):

> At 230° there is a strong condensed prominence of considerable height accompanied by no corresponding disturbance in the *Ca* spectroheliogram. There is a weak continuous spectrum accompanying the most condensed part, but there is no condensation in the 5303 ring. In the corona there are dark markings which can be traced down to this prominence. . . . . At 300° there is a large eruptive prominence of feathery structure but there is nothing to correspond in the spectroheliogram or in the photoheliogram. There is no strengthening in 5303 and nothing remarkable in the corona. At 330° there is a high massive prominence unassociated with *Ca* or photospheric markings and having no counterpart in 5303. This is worthy of comment as the prominence is canopied by a very remarkable arched structure and also the longest streamers shown on the photograph.[2]

It is evident that the intensity of the coronium ring 5303 is weakest near the sun's axis but strongest in the prominence zones. The maximum intensity is found always near prominences but does not necessarily coincide with prominences.

As already stated, the sun's axis in Plate IIIB is vertical; the left-hand drawing representing λ 5303 bears out the statements cited above. The streaks of continuous spectrum have the natural effect of increasing the intensities at the sun's limb. It is evident that 5303 is present but weak at the sun's poles. The contrast between the distribution in 5303 and 6374 is quite striking. On all spectra with both gratings the radiation in 6374 is much more uniformly distributed than in 5303—in fact, if it were not for the intensification caused by the continuous spectrum, the ring 6374 would appear about as intense at the sun's poles as at the solar equator. As expected, we find the greatest intensities in 6374 associated with the

[1] *Astrophysical Journal*, **55**, 73, 1922. [2] *Op. cit.*, p. 143.

prominence groups in southeast and northwest quadrants coinciding with the positions of greatest intensities in 5303. It is seen, however, that the radiation of 6374 always sticks close to the sun's edge and is more concentrated and more uniform than 5303.

The greatest surprise of all in comparing the images of 5303 and 6374 was to find how little they resembled each other in their structural details of greatest strength and how little either resembled the high-level lines of K and *Hα* of the chromosphere. These details are given in the drawings reproduced in Plate IV. Changes were noted in the details of the 5303 coronal ring with progress of time as shown in the different plates taken with the two gratings. Some of these changed appearances are photographic, owing to differences of exposure and development, but some are unquestionably due to motions. On account of the short-time interval, exact measurements of velocities are impossible. Some similarities can be detected between the faint streamers in the lines 5303 and 6374 when compared with Marriott's direct photographs, but in the stronger details few likenesses can be found. The direct photographs of the southeast section show the prominence structure more threadlike than in the K or *Hα* spectra. The direct photographs come from the integrated light of many wave-lengths, the photographic plate employed being sensitive to blue and violet light and not to green or red, but the glass of the camera lenses absorbs the violet. Hence the radiation from λ 5303 and λ 6374 can contribute nothing to the direct photographs, nor can the coronium lines in the far violet. Therefore, the direct photographs of the eclipse close to the sun's edge consist essentially of radiation from the high chromosphere and of light reflected by atoms and electrons. The prominences seen in these direct photographs consist mainly of radiation from H and K and from the hydrogen lines, not including *Hα*.

It is evident from the details in their structures shown by 5303 and 6374 that they cannot take their origin in the same atom, at least not in the same atom in the same state of ionization.

Hopfield[1] finds in the laboratory spectrum of neutral oxygen a line with a wave-length at 6374.29 and also two lines at 6300 and 6364 which agree in wave-length, within limits of error, with unidentified

[1] *Physical Review*, **37**, 160, 1931.

lines in nebulae. McLennan and his co-workers[1] have produced the green auroral line at λ 5577 in the laboratory and have found it to be caused by neutral oxygen. There is a remarkable agreement in wave-length between the laboratory value and that of the coronal line at λ 6374.28. Mere coincidence of wave-length, however, has been a trap which has waylaid many an able investigator in astrophysical science. As Hopfield has pointed out, the agreement in wave-length for this line causes "the terms which give rise to it to become of great interest. The most promising lead in their identification would be a study of the Zeeman pattern of this line."

ABSORPTION IN THE CORONA

Earlier in this paper it has been stated that the edges of the coronal spectral lines are sharp and well defined which rendered possible accurate measurements of wave-lengths. These sharp edges are shown in the accompanying reproductions. The cause of the sharpness is an apparent absorption of radiation at the base of the corona. As far as I know, a similar phenomenon has never before been observed in eclipse spectra. Obviously it is quite possible that the cause is a photographic or developer action known as the Eberhard effect. However, all the eclipse spectra taken by the writer were examined carefully, and there was found no similar absorption anywhere connected with any of the chromospheric lines even though these lines have very wide ranges in intensities. Compared to the thickness of the chromospheric layers the extent of the corona is enormous. There are consequently great differences in the temperatures and pressures found at the base of the corona and those at the higher reaches. Hence there seems to be no reason why these differences in temperature cannot cause absorption of radiation at the base of the corona.

The absorption effects found at the base of the 1930 coronal rings are most easily visible with the strongest lines of 5303, 3388, and 6374. Absorption is likewise visible in the fainter rings. Similar features are found in the 1905 and 1925 spectra taken by the concave grating.

[1] *Proceedings of the Royal Society*, A. **114**, 1, 1927: *Philosophical Magazine*, **6**, 558, 1928; L. A. Sommer, *Zeitschrift für Physik*, **51**, 451, 1928.

After the brilliant work by I. S. Bowen in finding the source of the lines of "nebulium," A. S. Eddington[1] has shown that on account of the great energy of the sun "coronium" cannot find its explanation from atoms in the corona in metastable states. No forbidden lines are found either in the ordinary solar spectrum or in the flash spectrum. However, it is quite possible that the strong coronal line at λ 6374 may finally be ascribed to neutral oxygen.

SIMILARITIES IN CORONAL LINES

While the present article was at this point in its preparation, the note from Stratton and Davidson[2] appeared calling attention to the differences in intensities between the coronal lines in 1926 and in 1929. These differences have already been alluded to, and the results are to be found in Table VI. The line at λ 3328 was a strong line in 1929. Grotrian[3] calls attention to this line visible alongside the neighboring high-level chromospheric line of Ti^+ at λ 3329.42. The 1926 spectra, which are of excellent definition and good dispersion, showed the chromospheric line of fine strength, but the coronal line was conspicuous by its absence. As already noted, 3643 and 3801 were weaker in 1929 than in 1926.

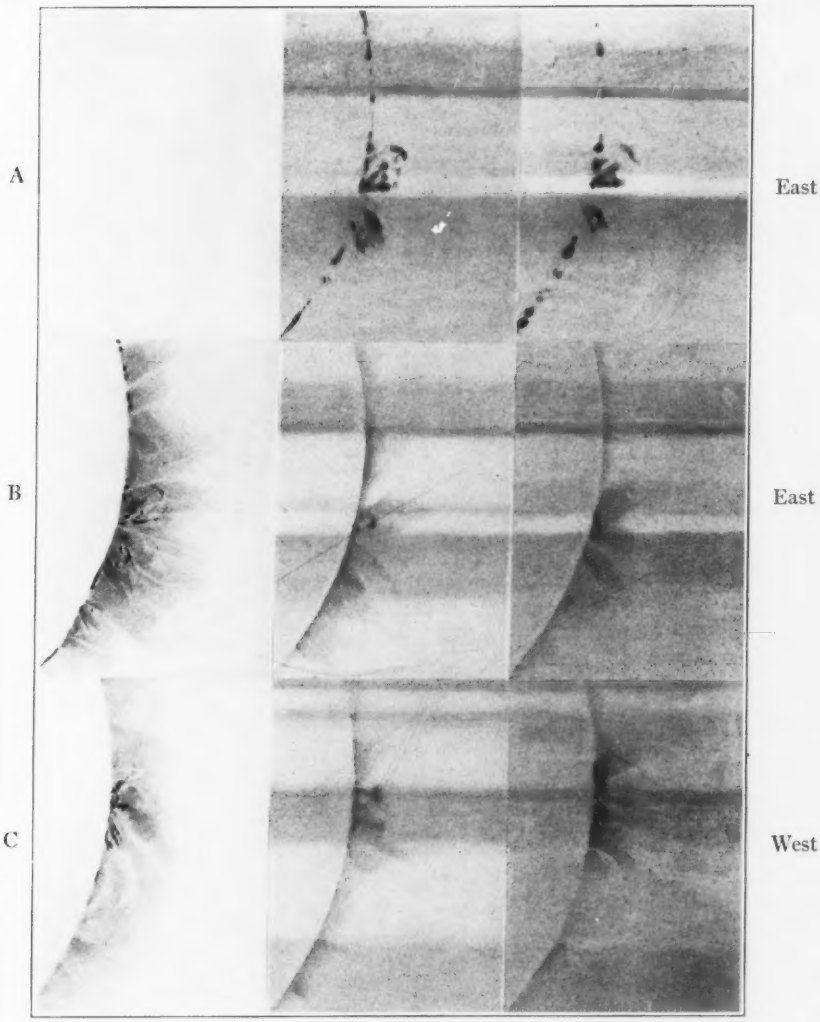
Stratton and Davidson summarize the similarities of coronal structure noted previously by others. Lockyer and Fowler place 4086, 4231, 4400, 4586, and 5303 in one group; 3801, 3987, and 4567 in a second; and 4359 in a third. Campbell and Moore have three groups: 3388, 3601, and 5303; 3801, 3987, and 4567; and 4231 by itself in the third group. Davidson and Stratton grouped 3388 with 3987; 3454 with 3643; and 3601 with 4086 and 5303. They further suggest that "3643 should go with 3801 and 3987," thus making one group of 3388, 3454, 3643, 3801, and 3987.

The 1930 slitless spectra make it very plain that coronium has a very uneven distribution at different position angles surrounding the sun. The limitations of the spectra taken with a slit are at once apparent. If the slit happens to fall on an intense part of the coronal ring, then all lines belonging to a group physically connected should

[1] *Monthly Notices of the Royal Astronomical Society*, **88**, 134, 1927.

[2] *Observatory*, **54**, 197, 1931. [3] *Loc. cit.*

PLATE IV



DRAWINGS MADE BY EMMA T. R. WILLIAMS FROM SPECTRA BY CONCAVE GRATING WITHOUT SLIT

A and *B* refer to the eastern section of the sun shown in Plates I and II, and *C* to the western section. (Please note that all positions in C are inverted.)

In *A* are given the K line of *Ca*+ and the *Hα* line of the chromosphere from spectra taken immediately following the first flash. In *B* and *C* are given (from left to right) details from Marriott's photographs near the beginning (*B*) and end (*C*) of totality, and the structure in the coronal rings of spectra at λ 5303 and λ 6374, respectively.

UNIV. OF MICH.

be intensified together; but if the slit crosses a fainter stretch of the corona, all lines of the group should be weakened together. Evidently the comparisons of intensities of lines at one eclipse with those at another (e.g., 1926 and 1929) may mean comparatively little, so much depends on the position angle of the slit. Unfortunately, for the purpose of discussing groups, most of the coronal spectra up to date have been taken with a slit, and, moreover, it must not be overlooked that the slitless spectra obtained at early eclipses have left much to be desired in the matter of definition.

As already noted earlier, the line λ 3601 is remarkably peculiar, missing in 1905 and very strong in both 1925 and 1930, the spectra of all three years having been taken with the same equipment and without slit. In the last two years, the lines are very intense on both limbs of the sun but in a very restricted region near the sun's equator. The line 4086 resembles 3601 very closely, and undoubtedly these form a pair. With either one or the other of these lines the following have been grouped: 3388, 4231, 4586, and 5303. No confirmation of this grouping is given by the grating spectra.

Chief interest naturally centers in the green line at 5303. The 1930 spectra, showing details that in shapes resemble eruptive prominences, exhibit the identical details in the line 3388 but in much weaker intensity on account of absorption by the speculum of the grating and the silver of the coelostat. The 1905 coronal spectra likewise show structural details similar in character in the two lines. It is interesting to find the two strongest lines, 3388 and 5303, unquestionably forming a pair. As already stated, 3601 and 4086 cannot be grouped with this pair.

The lines 3454 and 3643 certainly do not form a pair, the latter being missing on Grotrian's 1929 spectra while the former line is strong. Mitchell's 1925 spectra likewise show 3643 missing or doubtful. There seems little reason for grouping 3643 with 3801 and 3987, as suggested by Stratton and Davidson.[1] If the three lines form a group, their relative intensities must increase and decrease together in different eclipses. The grating spectra and also those of Dyson and of Lewis do not confirm this grouping.

All previous authorities have made a group of 3801, 3987, and

[1] *Observatory*, **54**, 197, 1931.

4567. The relative intensities of the three with prismatic spectra have been observed as follows: (1896) 3, 5, 8; (1898) 3, 5, 3; (1900–1901–1905, Dyson) 3, 5, 6; (1908) 3, 4, missing; (1926) 1, 5, 3. The relative intensities vary so enormously from eclipse to eclipse that it does not look reasonable to combine all these or to place any combination of these three lines into pairs. This conclusion is confirmed by the slitless grating spectra.

What line, or lines, are similar in physical characteristics to λ 3454, itself a strong line? As already stated, certainly not λ 3643. It cannot go with 3801 or 3987, and evidently not with 3388 or 5303, nor yet with 3801 or 3987. In recent years no one has combined the strong line 4231 with any other. It does not seem possible to group 3388 and 3987, as Davidson and Stratton have done. In fact, the only pairs left without suspicions are 3388 and 5303, and the other pair, 3601 and 4087.

Coronal spectroscopic work in the future needs information in the two following directions: (1) wave-lengths of greater precision, and (2) detection of similarities in structure in order to ascertain the atomic origin of the coronal lines. No advances can be made in either investigation unless with a fair dispersion of at least three prisms or 10 A per millimeter. With solar eclipses, observers should do as in other lines of scientific investigation—read the literature, study the problems, and design apparatus that will advance knowledge rather than attempt to do something simply because it is something. Eclipses are very spectacular phenomena and therefore may have a great publicity value. Eclipses unfortunately occur but seldom. On account of their rarity an individual, unless he has a fat pocketbook, is not in a position to gather apparatus to be used comparatively rarely in a lifetime. Therefore it is well that there are centers where eclipse equipment is accumulated. In the United States the Lick Observatory and the United States Naval Observatory have specialized in eclipses and have acquired valuable eclipse apparatus. In England there is the Joint Permanent Committee of the Royal and Royal Astronomical societies.

To attain the highest accuracy in wave-lengths a slit is desirable. The most useful form is a three-prism spectrograph designed to gather as much light as possible. To secure a wide range of wave-

lengths optical parts of quartz are necessary. Unfortunately a slit cannot be used with a grating—there is not enough light.

The surest method of detecting groups of coronal lines will evidently be to discover similarities in their structure, which is possible only with slitless spectra. In order to increase the contrast between the bright-line coronium spectrum and the continuous spectrum large dispersion is essential. This may be accomplished, as in the present investigation, by a concave grating, or by a prismatic camera by increasing the focal length (and also the aperture) of the camera. Unfortunately, to get the most information the optical parts should be of quartz, a seemingly impossible condition to impose for a problem that can be attacked so seldom. The eclipse of 1932 will furnish the opportunity of putting these recommendations into effect.

THE SHAPE OF THE CORONA

For half a century the shape of the corona has been connected with the activity of the sun as revealed by the sun-spot cycle. For the last forty years the dates of maxima and minima of spots have been as follows:

Maximum	Minimum
1893.6	
	1901.7
1905.6	
	1913.6
1917.6	
	1923.6
1928.5	

The recent maximum has been a curious one, with great activity but with the Greenwich mean areas of both spots and prominences showing peaks in 1926 and 1928 while the annual means of Wolf numbers steadily increased from the date of minimum in 1923.

In *Handbuch der Astrophysik*, 4, 317, 1929, there is stated the general problem of the dependence of coronal shape on solar activity. The eclipses of the last decade have been beautifully situated with respect to the sun-spot cycle and have added valuable information. The eclipse of 1922 took place shortly before minimum of spots; that of 1923 almost exactly at minimum. A year and a half after minimum came the 1925 eclipse, while those of 1926 and 1927 were just before, and 1929 and 1930 just after maximum.

The information on the activity of the sun as recorded in the sun-

spot cycle comes, as the name signifies, from observations on spots, their Zürich relative numbers, the Greenwich mean areas, the latitude of spots, etc., etc. Similarly observations made on prominences give also the numbers, mean areas, mean latitude, etc. The sunspot and prominence curves closely parallel each other. In a sense the information from prominences supplements that from spots in that the spots are phenomena observed on the face of the sun while the prominences are photographed only at the sun's limb.

To observe spots a moderate equipment—a mere telescope—is all that is necessary. The activity of the sun manifesting itself in spots can be observed as the spot moves across the face of the sun, measurements of polarity, etc., continued from day to day giving a fairly faithful badge of the relative activity of the sun. In comparison the prominences are transitory phenomena. Even if individual prominences were more permanent than they are, the rotation of the sun would carry them quickly out of sight. Occasionally when a total eclipse comes the direct photographs of prominences and the eclipse spectra can be compared with spectroheliograph photographs. Then we see the limitations of the latter method. The eclipse photographs on October 21 last showed the sun with a very stormy region in the southeast quadrant while the Mount Wilson spectroheliogram taken only a few hours earlier showed nothing particularly remarkable about the activity in this quadrant. Unless the prominence exhibits both height and contrast through masses of gases in eruption, it is usually not a conspicuous object on the prominence plates. Hence, taking all things together, it has been generally felt by the average astronomer that the information from spots gives a more reliable indication of the activity of the sun than is obtainable from observations of prominences. As already stated, however, the two types of observations supplement each other.

When attempts are made to find correlations between coronal disturbances and either spots or prominences, it is evident on the face of things that many more connections must always be found between prominences and coronal structure than between spots and corona. The spots are seen on the face of the sun while both the corona and prominences stretch out from the edge of the sun. It must not be thought that of necessity there must be a more intimate connection

between prominences and coronal activity than there is between sun-spots and coronal disturbances. The chance of a spot being near enough to the edge of the sun at the time of totality to disturb the corona, as in 1901,[1] is very slight. The eclipse photographs show prominences and disturbed regions in the corona, but from the nature of things cannot show spots. Unless the eclipse astronomer observes the spots on the final days before the eclipse—and he is usually too busy with a thousand and one things that must be done—or unless he looks up the literature afterward (and this is rarely done), the possible connections between individual spots and coronal disturbances pass unnoticed.

The first good photographs of coronal domes were obtained[2] by the Lick expedition in 1893. In describing the connection with prominences Miss Clarke states that "each pearly pavilion is erected over a red flame. Coincidences of this kind are of perpetual occurrence." However, for every prominence which shows this coincidence there are many more prominences which give no indication of overtopping coronal domes.

At the October, 1930, eclipse the high-level prominence group on the eastern limb at position angle 115° was connected with the very prominent "strawberry dome." By way of contrast, however, the longest streamer in the corona at position angle 150° was not connected with a high-level and therefore conspicuous group of prominences.

H. Ludendorff[3] has done a valuable piece of work for eclipse investigations in providing a simple method of measuring the shape of the corona. He has utilized photographs and half-tone reproductions to draw roughly by eye lines of equal intensity (isophotes) surrounding the corona. From simple measures easily carried out two quantities, a and b, were determined, the value a being nearly constant for all eclipses while b varies, being zero for the eclipse of "sun-spot maximum" type, the shape being nearly circular in outline, while b has its maximum value, the eclipse being most elliptical in shape for the typical "sun-spot minimum" type.

[1] *Eclipses of the Sun*, p. 326, 1924.

[2] *Handbuch der Astrophysik*, **4**, 320, 1929.

[3] *Sitzungsber. der Preussischen Akademie der Wissenschaften*, **16**, 185, 1928.

Mitchell[1] rearranges Ludendorff's data and finds a closer connection between the coronal shape and sun-spot numbers than there is with the phase in the spot cycle measured from the time elapsed from minimum or maximum of spots.

Bergstrand[2] also takes Ludendorff's figures and applies a correction to the values of the isophotes in polar regions to allow for the effect of equatorial and mid-latitude streamers being superposed over polar rifts. He finds a correlation with sun-spot numbers but a closer connection with prominences in high-latitude zones.

Lockyer[3] makes a very valuable compilation by collecting into one diagram all the information, beginning with the year 1860. He gives sun-spot information from mean daily areas and the latitudes in both hemispheres, and similarly for prominences. He divides the coronas into three shapes: "polar" or irregular, "intermediate" or square, and "equatorial" or wind vane.

On account of the connection between coronal disturbances and prominences already alluded to, and on account of the fact that prominences are much more widely distributed in heliographic latitudes than are spots, it is not surprising that Lockyer finds a close correlation between the shape of the corona and prominences, the polar corona occurring when prominences are near the poles of the sun.

The division of the coronal shapes into three types is a very rough classification, depending, as it does, frequently on the impression made on eclipse observers during the fleeting and nerve-racking seconds of totality. Speaking as an eclipse observer of long experience, with always a strenuous spectroscopic program on my hands, I must confess that I have had little opportunity during totality of acquiring a calm and judicial opinion of the shape of the corona. In plotting the 1930 eclipse in the sun-spot cycle Lockyer has used my statement (radioed immediately after the eclipse and before I had seen any of the developed photographs) to indicate that the 1930 eclipse more nearly approximated the minimum type of corona than the eclipse of 1929.

[1] *Handbuch der Astrophysik*, **4**, 338, 1929.

[2] *Arkiv för matematik, astronomi och fysik*, A, **22**, No. 1, 1930.

[3] *Monthly Notices of the Royal Astronomical Society*, **91**, 797, 1931.

Instead of this crude classification into types, it is better to use the values of b determined by Ludendorff beginning with the eclipse of 1893, even though this latter is admittedly rough. Omitting the refinement introduced by Bergstrand, we may plot $b=0.00$ for the top line of Lockyer's diagram (sun-spot maximum type) and $b=+0.24$ for the bottom line (minimum type of corona). If the shapes of the different eclipses are defined and plotted by this simple method, then it is found that very few of the eclipses actually fall on the sun-spot curve, but on the contrary they practically all lie consistently and persistently to the left, or earlier in time on the diagram. If the curve drawn by Lockyer to represent the shapes of the coronas is shifted bodily by about two years toward an earlier date, then all the eclipses since 1893 fall symmetrically on or near his curve.

In the *Handbuch der Astrophysik* Mitchell states:

> Four eclipses, those of 1896, 1898, 1900 and 1901, took place at an average of 2.6 years before the sun-spot minimum of 1901.7; the quantity b had a mean average of +0.22. The eclipses of 1914, 1923 and 1925 occurred on the average only 1.0 years after the minimum of 1913.6 and 1923.6 and yet the corona then differed more ($b=+0.15$) from the typical minimum corona than at the longer interval of 2.6 years before minimum. In fact, the eclipse of 1923 took place almost exactly at minimum of spots, and yet the value of $b=+0.18$ had the same value as the average of the two eclipses of 1896 and 1898 which happened more than four years before the date of minimum of spots.
>
> Undoubtedly, the great extensions of the corona which are associated with the time of the minimum of spots do not take place *at the time* of sun-spot minimum but *before* that time by approximately two years.

It was further noted that the corona of January 14, 1926,

> had lost all of the characteristics of the minimum shape of corona and closely resembled that associated with maximum of spots even though the time was nearly two years before the expected maximum of spots. The corona of June 29, 1927, was distinctly that of maximum type.[1]

Now that we have a record of the two recent eclipses, it may be added that the eclipses of May 9, 1929, and October 21, 1930, had lost their "maximum" characteristics and were distinctly "intermediate" in type. Hence we seem forced to a conclusion, similar to that found for the minimum type of corona, namely, *that the maxi-*

[1] *Op. cit.*, p. 318.

mum or polar type takes place from one to two years before maximum activity on the sun as derived from data as to spots and prominences.

As is well known and as is shown by Lockyer's diagram, about two years before the sun-spot curve shows a minimum, the new cycle of spots arises in northern and southern heliographic latitudes. About at the same time the new prominence cycle begins in high latitudes, 40° or more away from the equator, this cycle being distinct from that occurring in mean latitudes. As the activity of the sun increases, the spots draw in toward the equator and increase in number and size; the high-latitude prominences progress to still higher latitudes and also increase in activity. At sun-spot minimum there are two spot zones and two prominence zones in activity in each hemisphere. On the assumption that the intensity of the coronium lines vary with the sun-spot cycle, Mitchell[1] calls attention to the great strength of the emission line λ 6374 as an indication of increased solar activity at the 1925 eclipse, a year and a half after sun-spot minimum.

After three hundred years of observations we are forced to confess that the eleven-year curve must still be regarded as erratic. The solar activity from numbers and areas of spots or from frequency and areas of prominences gives curves which are similar but are not identical. Other allied curves, terrestrial magnetic phenomena, etc., also show vagaries. It is still unsafe[2] to predict, even a few years in advance, what the sun-spot cycle is going to do. Recognizing these limitations, or, in other words, realizing that the sun has sporadic and unexpected bursts of activity, it is well not to make too great claims for dependence on the sun-spot curve.

We have two main types of corona: the so-called "minimum-type," with pronounced polar brushes or rifts and extended streamers lying near the sun's equator which have been seen to distances of ten solar diameters; then there is the "maximum-type" nearly circular in outline, "shaped like a gigantic dahlia." Between the two the corona is "intermediate" in type. From the foregoing investigation it appears evident that the corona takes on the "minimum," "intermediate," and "maximum" types always consistently about two years earlier than expected from the investigations carried out on spots and prominences. In other words, the new cycle of solar

[1] *Ibid.*, p. 341. [2] Cf. Mitchell, *Eclipses of the Sun* (2d ed.), p. 120.

activity, which manifests itself both in spots and in prominences two years before the time of sun-spot minimum, makes itself felt immediately not only in the changed shape of the corona, but in the increased strength of the emission lines of coronium.

As the corona takes its shape primarily from the lengths and position angles of the longest streamers, and as the photographs taken at and near the eclipse of October, 1930, show that the longest streamer was connected with solar activity that had persisted for several days, it is evident that the corona can have no constant shape, but no doubt it varies from day to day, depending on the location of the sun's activity. The corona we happen to photograph during the few fleeting seconds of totality is a temporary phenomenon which will submit itself to law with great reluctance.

Without attempting too great generalities, it is perhaps simpler and more convincing to state that the great and unexpected activity in the corona which was manifested in the eclipse of September, 1923, and which has continued with unabated energy up to and through the time of the eclipse of October, 1930, is simply a reflection of the unusual activity of the sun in that interval, as indicated by the observations of spots and prominences.

LEANDER MCCORMICK OBSERVATORY
UNIVERSITY OF VIRGINIA
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DOPPLER EFFECTS IN HYDROGEN CANAL RAYS OF UNIFORM ENERGIES

By H. F. BATHO AND A. J. DEMPSTER

ABSTRACT

Positive ions were produced by bombarding hydrogen with low-voltage electrons from a hot cathode. The ions formed passed beside the cathode into a strong field where they were accelerated by potentials up to 15,000 volts. The ions then passed into an observation chamber, where the light emitted by the accelerated particles was photographed with a large three-prism spectrograph. With the usual canal-ray tubes broad displacements are obtained as Doppler effects due to the velocity distributions in the ions, maxima are sometimes present suggesting ions of various masses, and the observed displacement is always considerably less than that calculated from the potential difference on the tube. With the present tube sharp displaced lines of the Balmer series are obtained indicating homogeneous velocities, the displacements agree with those calculated from the potential for atomic ions, molecular ions, and triatomic molecular ions. These ions break up in the observation chamber giving hydrogen atoms which emit the Balmer series lines with Doppler effects corresponding to the velocities of the ions. At low pressures the displaced line due to the molecule ion becomes the strongest as suggested by previous experiments on the positive-ray analysis of ionization products.

The discovery of the Doppler effect in the radiation from canal rays by J. Stark[1] has been very important in verifying our theories of the processes going on in a discharge tube. The canal rays or positive rays produced in an ordinary discharge tube are found to consist of particles moving with a great variety of velocities. This is due to two causes: first, the charged atoms or molecules are formed at various places in the discharge tube and fall through different fractions of the potential applied; in the second place, the rapidly moving ions may be neutralized and pass through part of the electric field as neutral particles. As a consequence the spectral lines emitted by the moving particles in the direction of motion are displaced to the violet by various amounts and give rise to a broad "displaced intensity." In hydrogen under certain conditions F. Paschen[2] observed two maxima in the displaced intensity. J. Stark and W. Steubing[3] found that three maxima sometimes appeared. The three displaced maxima have been interpreted as due to the superposition of radiation from particles which had been accelerated as hydrogen atoms, hydrogen molecules, and triatomic hydrogen molecules. These mole-

[1] *Physikalische Zeitschrift*, **6**, 893, 1905.

[2] *Annalen der Physik*, **23**, 251, 1907.

[3] *Ibid.*, **28**, 974, 1909.

cules are later disrupted at some collision, forming atoms which retain the original velocity, and emit the line spectrum of atomic hydrogen. H. Krefft[1] has also observed three maxima under certain conditions and found that the displacements of the maxima at low potentials (3000–13,000 volts) varied approximately inversely as the ratios $1:\sqrt{2}:\sqrt{3}$. At higher potentials the middle maximum disappeared and the ratio of the displacements of the two remaining maxima became greater than 1:2. Krefft also found that the maximum Doppler displacement observed was only 70 per cent of that to be expected for hydrogen atoms as calculated from the potential on the tube.

In some recent experiments W. Riezler[2] passed a beam of a canal ray from an ordinary discharge tube through a magnetic field and observed the Doppler effect due to charged particles which had been deflected through a definite angle. A displaced line was observed which agreed with the velocity of hydrogen atoms, calculated from the amount of the magnetic deflection. By increasing the magnetic field two other displaced lines could be obtained whose velocities corresponded to those calculated from the magnetic deflections for hydrogen molecules and triatomic hydrogen molecules.

The purpose of the present experiments was to observe the Doppler effects when the charged particles all fall through the same potential difference. With rays of homogeneous velocities, sharp displaced lines might be expected. Two methods were tried for obtaining rays of uniform velocity. The first is illustrated in Figure 1. It is based on the method used by J. J. Thomson[3] and C. T. Knipp[4] in the positive-ray analysis of ionization products and on the method used by Dempster[5] in studying primary and secondary ionization products. The gas is ionized by electrons emitted by *C* and accelerated to *A* by a low potential. The ions formed pass through holes in the plate *D* and are accelerated by a large potential difference between *D* and *E*. The rays pass through holes in *E*, and the light emitted is observed through a window at the end of the tube. The

[1] *Ibid.*, **75**, 75, 1924. [2] *Ibid.*, **2**, 429, 1929.

[3] *Philosophical Magazine*, **18**, 838, 1909.

[4] *Ibid.*, **22**, 926, 1911.

[5] *Ibid.*, **31**, 438, 1916; *Physical Review*, **8**, 651, 1916.

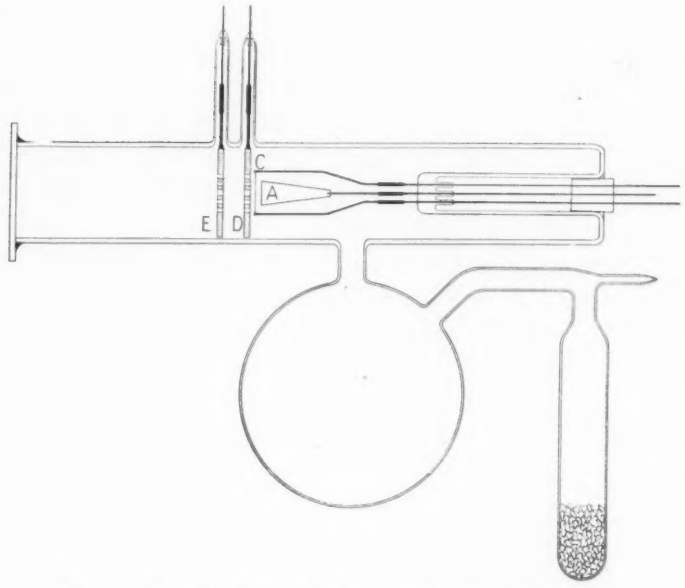


FIG. 1.—Doppler effect tube for particles of uniform energy

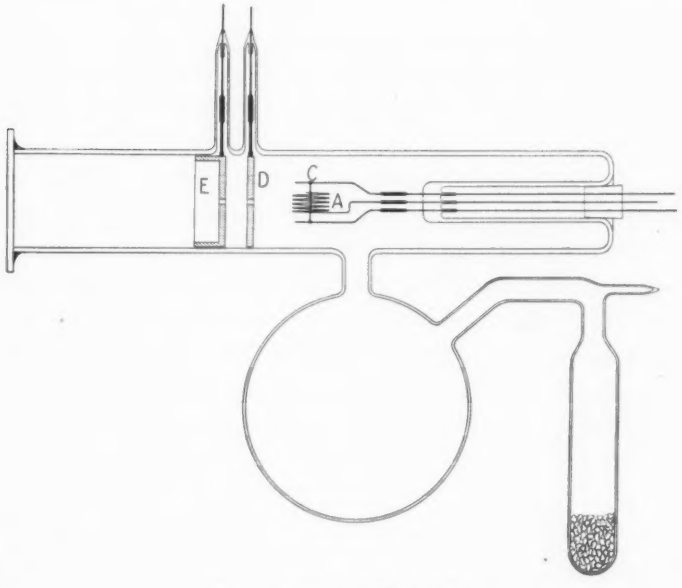


FIG. 2.—Doppler effect tube

hydrogen pressure is made so low (by immersing a charcoal tube to various depths in liquid air) that no collisions or change of charge would be expected in the small space *DE*.

A second method illustrated in Figure 2 was also tried. It is a modification suggested by the experiments of M. L. E. Oliphant.[1] A discharge is formed between the hot cathode *C* and the spiral wire anode *A*. The ions formed are drawn to the plate *D* and accelerated as before. Much greater intensities were obtained by the first method, and it was used exclusively in the observations. The potential between *C* and *A* was approximately 200 volts, and various fields up to 15,000 volts were applied between *D* and *E*. The light behind *E* was photographed through the end of the tube with a large three-prism Steinheil spectrograph. Exposures of three to ten hours were necessary.

OBSERVATIONS

It was found that sharp displaced lines were obtained, indicating that the great majority of the ions retained their charge while being accelerated in *DE* (Figure 1). On some photographs at high pressure there was also a broad band of intensity less displaced than the lines, which may be due to those ions that become neutralized in the condenser. On some photographs three displaced lines were observed, with displacements inversely proportional to 1, $1/\sqrt{2}$, and $1/\sqrt{3}$. The line with the greatest displacement was always much fainter than the other two, and on several plates only the inner two could be measured. The results are given in Table I. The potential on the condenser *DE* was calculated from a spark gap in parallel with the tube. This yields only approximate values of the potential, and the uncertainty is probably sufficient to explain the differences between the observed displacement in angstroms (col. 5), and the value calculated for the velocity of singly charged molecules as given in column 4. Column 7 gives the observed displacement in angstroms for the most displaced line, and column 6 gives the observed value for the middle line multiplied by $\sqrt{2}$. This is the displacement to be expected if the line is emitted by hydrogen atoms which have been

[1] *Proceedings of the Royal Society*, **124**, 228, 1929; **127**, 375, 1930. J. J. Thomson (*op. cit.*, **16**, 673, 1908; **18**, 838, 1909) accelerated ions from a discharge tube through a hole into a side tube.

accelerated by the same potential as hydrogen molecules. The last two columns give the observed values for the least displaced line and the displacements calculated for H_3^+ ions accelerated by the same potential as the molecular ions. It is seen that the agreement for the H_1 and H_3 ions is as good as could be expected.

We are thus led to conclude that the molecular and triatomic molecular ions dissociate into atoms soon after leaving the condenser and

TABLE I

CALCULATED AND OBSERVED DISPLACEMENTS IN ANGSTROMS FOR HYDROGEN LINES FROM SOURCES ACCELERATED AS CHARGED MOLECULES, CHARGED ATOMS, AND CHARGED TRIATOMIC MOLECULES

Plate	Volts	Line	H_3 Cal.	H_3 Obs.	$H_3\sqrt{2}$	H_1 Obs.	$H_3\frac{\sqrt{2}}{\sqrt{3}}$	H_3 Obs.
19.....	12,000	$H\beta$	17.4	15.8	22.4	22.3	12.9	12.4
.....	.....	$H\gamma$	15.5	14.3	.....	.....	11.7	11.9
20.....	5300	$H\gamma$	10.3	8.8	12.45	12.1	7.18	7.1
21.....	5300	$H\gamma$	10.3	8.4	.....	.....	6.83	7.07
22.....	15,000	$H\beta$	19.5	18.6	26.3	26.0	15.2	14.9
.....	.....	$H\gamma$	17.3	17.4	.....	.....	14.2	14.3
23.....	12,000	$H\gamma$	15.5	13.8	.....	.....	11.25	11.2
24.....	12,000	$H\gamma$	15.5	14.1	.....	.....	11.5	11.5
25.....	12,000	$H\gamma$	15.5	13.8	.....	.....	.....	.....
.....	.....	$H\delta$	14.7	14.4	.....	.....	.....	.....
26.....	12,000	$H\gamma$	15.5	13.8	.....	.....	.....	.....
.....	.....	$H\delta$	14.7	14.4	.....	.....	.....	.....

that the resulting hydrogen atoms emit the Balmer series lines, and continue on in the original direction without appreciable loss of velocity. The moving atoms excite light in the gas and are continually re-excited themselves. This phenomenon of the dissociation of hydrogen molecule ions into atoms is well known from experiments on positive-ray analysis.[1] An ion may be accelerated as a molecule and then deflected magnetically as an atom.

The three types of charged ions are formed in the low potential discharge CA. If the pressure is very low, charged molecules are the only ions obtained. At higher pressures the molecule ions associate with molecules of the gas to form triatomic molecular ions and also

[1] J. J. Thomson, *Rays of Positive Electricity*, pp. 66–67; H. D. Smyth, *Physical Review*, **25**, 452, 1925; A. J. Dempster, *Philosophical Magazine*, **3**, 119, 1927.

dissociate to give hydrogen atoms.[1] The relative intensity of the displaced spectral lines would depend, in the first place, on the relative numbers of the three types of ions furnished by the low-voltage discharge. In the second place, the velocity with which a hydrogen atom is moving probably influences its efficiency as a radiator. E. Rüchardt[2] has shown that with high velocities the free path in the charged state is increased so that neutralizations and light-emissions would occur less frequently than at lower velocities. This is probably the cause of the unexpected faintness of the most displaced line. Experiments with various pressures and velocities may be expected to throw light on the relative intensities observed.

RYERSON PHYSICAL LABORATORY
UNIVERSITY OF CHICAGO
September 1931

NOTE ON DOPPLER EFFECTS IN NOVAE

In a discussion of these experiments Professor T. R. Hogness pointed out the similarity in appearance of these Doppler effects with the two displaced absorption lines that are observed in some stellar novae, at a certain stage of their development. This might support an interpretation of the two velocities as arising from the original ejection of a mixture of atomic and molecular hydrogen from the star. Through the kindness of Professor Frost and Mr. Elvey several spectra of Nova Geminorum No. 2 (1912) and Nova Aquilae No. 3 (1918) were examined. Some rough measurements of the displacements indicated velocities inversely proportional to 1 and $\sqrt{2}$. These are the ratios of the velocities assumed by hydrogen atoms and molecules when accelerated by the same forces. The sharpness of the displaced absorption lines and the changes in the Doppler effects suggest electrical forces, as would be necessary if we attribute the double displacement of an iron line to singly and doubly charged iron atoms.

[1] A. J. Dempster, *Philosophical Magazine*, **31**, 438, 1916; H. D. Smyth, *loc. cit.;* T. R. Hogness and E. G. Lunn, *Physical Review*, **26**, 44, 1925.

[2] *Annalen der Physik*, **71**, 377, 1923.

THE SPECTRUM OF DOUBLY IONIZED CERIUM[1]

By ARTHUR S. KING and ROBERT B. KING

ABSTRACT

The *spark spectrum of cerium*, when excited by a very intense discharge, shows in the *near ultra-violet* many strong lines not found in the arc spectrum, in which the lines of *Ce* II are prominent. The writers have measured *280 lines* of this character from λ *2167 to* λ *3544* and noted their *intensity* and *degree of diffuseness*. These spark lines probably belong for the most part to *doubly ionized cerium*, although 5 of the lines measured have previously been ascribed to *Ce* IV.

The presence in the ultra-violet spark spectrum of cerium of a large number of lines probably belonging to the doubly ionized atom was noted by one of the writers[2] some years ago. This observation was made in the course of a comparison of the furnace, arc, and spark spectra of cerium,[3] which showed the response of various groups of lines to different excitations. It was noted that the lines of neutral cerium, relatively few in the ultra-violet, are excited best by the furnace and that in the arc they are faint, the predominant lines of the arc in this region belonging to *Ce* II. This latter conclusion, in the lack of any analysis of the cerium spectrum, is based on the fact that the stronger lines of this group appear faint in the furnace and may be quenched by the addition of a substance of low ionization potential, a criterion frequently used in the selection of lines belonging to ionized spectra.

In the spark spectrum, beginning at λ 3550 and proceeding toward shorter waves, we find lines peculiar to the spark which may be assumed to belong to an ionization higher than the first. Many of these are very strong. At first they are interspersed with *Ce* II lines; then the latter become more infrequent until the lines of multiply ionized cerium make up the whole spark spectrum. Some of the strongest are given in the list of spark lines of Exner and Haschek;[4] a very intense discharge with large capacity is required,

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 441.

[2] A. S. King, *Physical Review*, **30**, 366, 1927.

[3] *Mt. Wilson Contr.*, No. 368; *Astrophysical Journal*, **68**, 194, 1928.

[4] *Spektren der Elemente*, **3**, 1912.

however, to bring out the 280 lines photographed by the writers as far as λ 2167.

Of the spark lines listed in the present paper, some, although probably only a few, belong to trebly ionized cerium. Gibbs and White[1] report having photographed the spark spectrum in this region with a stigmatic spectrograph, which brought out a conspicuous concentration at the electrodes of the pair λ 2456.86 and λ 2778.24. The frequency difference of these lines indicated that they belong to *Ce* IV. The number of lines classified was raised to eight by J. S. Badami,[2] whose list includes λ 2180.70, λ 2350.16, and λ 2430.31 in the region we have examined. These five *Ce* IV lines are all strong on our plates, and it is possible that others are present in our list, although probably most of the trebly ionized lines lie farther in the ultra-violet.

As far as λ 2500 the spectrograms were made with the second order of the 15-foot concave grating (scale, 1.86 A per millimeter), while the shorter wave-lengths were photographed in the first order. A solution of cerium nitrate was used on electrodes of Acheson graphite, a comparison with the spectrum of untreated graphite being made for the elimination of the carbon lines. The selection of multiply ionized lines was based on their non-appearance in the cerium arc, the spectrum of which was photographed adjacent to that of the spark and so strongly exposed that the typical *Ce* II lines were fully as intense in the arc as in the spark spectrum. For the wave-length measurements a special set of spectrograms was made by the usual method of taking adjacent exposures of an iron arc before and after photographing the cerium spark. The cerium lines were measured from well-established iron standards, largely from the list of Jackson;[3] for standards below λ 2327, however, we have used a list of unpublished values, largely recent measures of K. Burns, kindly supplied by W. F. Meggers and C. C. Kiess. The best plates were measured by each of the writers, four sets of measures being made for the shorter wave-lengths. The close agreement of these independent measures, together with the high quality

[1] *Physical Review*, **33**, 157, 1929.

[2] *Proceedings of the Physical Society of London*, **43**, 53, 1931.

[3] *Proceedings of the Royal Society of London*, A, **130**, 395, 1931.

TABLE I

WAVE-LENGTHS OF DOUBLY IONIZED CERIUM LINES

λ	Intensity	λ	Intensity	λ	Intensity
2166.95	20	2378.48	6	2504.454	6s
2169.55	6	2379.5	1	2509.5*	1
2180.70*	100	2380.18	200	2511.745	10
2183.8	1	2382.33	30	2513.34	3
2188.9	1	2385.11	15	2514.864	4s
2203.22	6	2386.23	3h	2515.77	4h
2207.30	8	2390.7	1	2517.6	1h
2210.7	2	2393.00	2h	2518.555	8
2218.16	12s	2395.10	60	2522.11	4h
2222.06	100	2397.66	3s	2525.1	1
2225.12	125	2398.76	8h	2532.040	100
2227.88	40	2400.72	10h	2537.6	2h
2228.10	50	2404.44	6h	2539.43	20h
2236.95	4	2406.31	20h	2543.110*	8s
2238.69	8	2408.15	30s	2544.39	3h
2241.30	10	2410.41	30h	2547.92	5h
2242.35	80	2411.06	6h	2548.72*	10?s
2244.18	8s	2415.21	3s	2548.79*	5?
2249.31	15s	2415.74	60h	2551.75	15h
2264.91	50	2417.11	30h	2553.28	12s
2266.95	10s	2418.44	10h	2554.3*	1
2268.22	25	2419.03	6h	2557.628	30h
2282.25	6	2423.20	10h	2560.442	10h
2284.64	2	2428.68	15s	2562.6	1
2287.85	30s	2430.31*	60	2563.450	6
2293.80	4	2431.51	300	2565.44	3h
2297.79	3	2433.57	3	2566.02	2h
2298.2	1	2439.87	250	2567.02	4h
2298.75	20	2441.69	20h	2569.21*	4
2299.96	4	2444.93	10h	2573.17*	8s
2300.70	80	2445.55	5	2575.06	20h
2302.14	100	2454.37	50s	2577.828	80h
2312.83	8	2456.86*	125	2578.34	30s
2314.39	2	2458.56	2h	2579.17	6
2315.91*	8	2460.86	2s	2584.87	70h
2317.40	100	2461.55	2	2588.58	2
2318.70	200	2462.99	10s	2591.19	15h
2324.37	50	2464.41	3	2592.38	2s
2327.95	3	2465.49	4h	2599.18	30h
2329.92	6s	2470.00	150	2599.41	1s
2330.19	4	2471.81	15h	2600.408	20h
2337.71	25	2472.71	4	2601.32*	4s
2345.26	2	2473.4	1	2603.646	400
2350.16*	200	2475.3	1h	2604.078	4s
2356.8	1h	2477.31	40	2605.3	2h
2362.58	40	2479.50	50	2608.114	150h
2367.81	30s	2483.88	60	2609.94*	4
2371.15	4s	2484.31	5s	2610.91	4h
2372.39	300	2490.35	3s	2614.58	3h
2373.44	6h	2497.56	60	2615.93	60h
2377.13	*50	2498.98	2	2616.1	8h
2377.53	40	2503.605	10	2617.72	2h

TABLE I—*Continued*

λ	Intensity	λ	Intensity	λ	Intensity
2619.80*	2s	2743.736	60s	3057.575	100
2620.68	2h	2748.936	50s	3076.82	6h
2621.151	15	2754.912	80	3085.089	200
2622.753	4s	2768.339	150	3088.022	3
2623.36	2	2774.473	8s	3088.86	5h
2623.83	4h	2778.243*	60	3102.335	4
2624.86	3	2780.59	3h	3106.974	200
2625.68	1	2795.158	8	3110.516	200
2629.773	4	2798.1	1	3110.71	4
2630.7	1	2801.824	10s	3118.379	2
2631.88	30h	2802.408	10s	3121.548	400
2634.08	4h	2806.3	1	3122.93*	4h
2637.953	1	2817.1	2	3125.28	2
2638.72	3	2820.8*	1	3126.21	1
2639.57	4	2822.648	8	3141.247	250
2649.418	50	2833.868	8	3143.956	200
2654.48	6h	2840.7	1h	3147.05	300
2655.71	20h	2845.19	10	3163.644	2
2658.6	3h	2846.4	2	3165.536	25h
2662.836	30s	2847.3	3h	3168.02*	25h
2663.80	10h	2848.2	2h	3190.67	1
2665.7	1h	2849.372	80	3191.41	2
2668.69	8h	2861.416*	15	3210.48	3
2671.9	1	2873.722	25	3228.564	400
2672.857	10s	2874.2*	20?	3252.95	1
2673.3	4h	2907.064	30	3261.61	2
2673.6	1	2908.804	2	3267.72	4
2675.08	4h	2923.84*	100	3267.92	6h
2675.6	2h	2925.283	80	3280.78	2
2679.2	1	2927.258	10	3353.262	150
2681.03	2h	2931.558	100	3395.735	50
2685.99	10h	2944.3*	15	3398.910	20
2686.74	10h	2948.564	15	3427.332	125
2694.857	6s	2973.716	50	3443.609	150
2705.026	2	3011.493	8	3454.368	150
2714.4	1	3022.736	200	3459.374	200
2717.22	10	3025.73	8	3470.894	300
2719.329	60s	3031.559	500	3497.755	60
2730.069	60s	3048.2	2	3504.596	100
2733.4*	3h	3055.585	600	3543.999	80
2738.861	3h	3056.556	125		
2741.688	5	3057.214	200		

NOTES TO TABLE I

2180.70 Ascribed to *Ce* IV.

2315.91 May be double.

2350.16, 2430.31, 2456.86 Ascribed to *Ce* IV.

2509.5 Close to carbon line λ 2509.1.

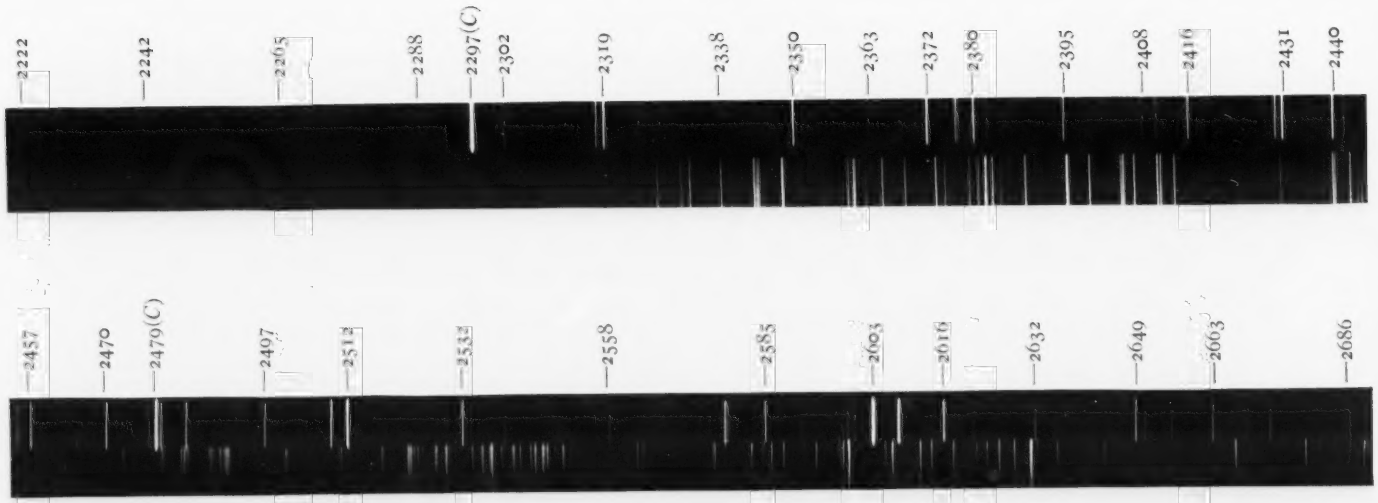
2543.110 May be *Ce* II much enhanced.
2548.72, 2548.79 Not fully resolved.
2554.3, 2569.21, 2573.17, 2601.32, 2609.94, 2619.80 May be faint *Ce* II lines much enhanced in spark.
2733.4 Very wide.
2778.243 Ascribed to *Ce* IV.
2820.8 *Ce* II line on violet side.
2861.416 *Ce* II line on violet side.
2874.2 Probably *Ce* III, on red side of *Ce* II λ 2874.135.
2923.84 Coincides with faint *Ce* II line.
2944.3 Probably *Ce* III, on violet side of *Ce* II λ 2944.354.
3122.93 To violet of *Ce* II line.
3168.02 Blend *Ce* II λ 3167.912.

of the standards, justified giving three-place values for many lines on the second-order plates. As is usual in spark spectra, none of the lines was strictly sharp; but unless dissymmetry results from an excitation higher than that required for the production of a given line, an appreciable width does not prevent measurements of high precision. The spark excitation used for the *Ce* III lines is that suitable for their initial appearance, and dissymmetry is therefore at a minimum.

Distinct differences in structure were found, varying from lines almost as narrow and sharp as those of *Ce* II to lines, usually of low intensity, showing a pronounced haziness. In Table I this difference is indicated by "s" after the intensity when the line is sharp and "h" when it is hazy, while lines of moderate widening are left without special designation. The hazy lines, beginning at λ 2373, may be expected to belong to much higher energy-levels than those which are decidedly sharp or show only a moderate degree of widening, as is the case with most of the very strong lines. Lines too faint for the comparator were measured with a glass scale; the wave-lengths of such lines are given to 0.1 A. An asterisk (*) after a wave-length refers to a note at the end of the table.

Plate V gives an enlargement of the region of shorter wave-length, with comparison spectra of the iron arc. Differences in degree of

PLATE V



SPARK SPECTRUM OF CERIUM, WITH COMPARISON SPECTRUM OF IRON ARC BELOW

UNIV. OF MICH.

diffuseness may be seen among the cerium lines, almost all of which are of multiple ionization. Plate VI shows the arc and spark spectra in the region where *Ce* III lines occur among those of *Ce* II. The *Ce* III lines may be identified by their absence from the arc spectrum. Occasionally, lines occur in the arc in close, though not exact, coincidence with lines of *Ce* III; but such arc lines never coincide with the strongest spark lines, and the agreement is not more frequent than is to be expected in a spectrum as rich as that of *Ce* II.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
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STUDIES IN PECULIAR STELLAR SPECTRA

III. ON THE OCCURRENCE OF EUROPIUM IN A-TYPE STARS

By W. W. MORGAN

ABSTRACT

Thirteen stars of spectral types A0–A3 have been found which show the two strongest lines of Eu^+. Seventeen other stars have a line in their spectra coinciding in position with the strongest Eu^+ line, which cannot be accounted for by any other element. These stars, together with α^2 Canum Venaticorum, seem to make up a group of "europium stars" in the early subdivisions of spectral type A.

1. The first announcement of the detection of the rare earth europium in stellar spectra was made by J. Lunt[1] in 1907. From measures of the radial velocity of α Bootis and β Geminorum he found that the *Ca* I line at λ 4435.690 (I.A.) was shifted 0.049 A to the violet of its normal position in α Bootis and 0.040 A in the case of β Geminorum. He found confirmation of the discordant velocity from measures of radial velocity made at the Yerkes and Lowell observatories. Altogether eight stars were listed, of which α Bootis was common to all three sources. On the assumption that an unknown line of equal intensity with *Ca* I 4435.690 was the cause of the discordance, he identified the disturbing line with *Eu* 4435.59. He states that there are strong lines in the spectrum of Arcturus in the positions of the two strongest europium lines at λ 4129 and λ 4205. From an examination of plates of Arcturus I have come to the conclusion that the identification of the disturbing line at λ 4435 with europium is difficult to establish, since the calcium doublet is well marked and both of the stellar lines at λ 4129 and λ 4205 are probably blends in the spectrum of the star.

L. E. Jewell[2] first suggested the identification of three lines in the flash spectrum with europium from plates taken at the eclipse of the

[1] *Proceedings of the Royal Society of London*, A, **79**, 118, 1907.

[2] *Publications of the United States Naval Observatory* (2d ser.), **4**, App. I, PD-121, 1905.

sun in 1900. A more complete discussion was made by F. W. Dyson[1] from spectra obtained at the eclipses of 1900, 1901, and 1905. Table I gives his identifications of the europium lines in the flash spectrum with the laboratory wave-lengths and intensities from Exner and Haschek. All of the data are taken from Dyson, and the wave-lengths are expressed in the old Rowland system.

In 1913 F. E. Baxandall[2] announced the identification with the strongest lines of europium of two of the lines showing the most marked variation in intensity in the spectrum of α^2 Canum Venaticorum. From a comparison with laboratory wave-lengths he identified five other lines with europium by means of measures made by

TABLE I

EUROPIUM IN THE CHROMOSPHERE (DYSON)

CHROMOSPHERE		SUN	IDENTIFICATION	LABORATORY		
λ (Row.)	Int.	Int.		λ (Row.)	Intensity	
					Spark	Arc
3907.28	2	.....	*Eu*	3907.3	30	30
3972.02	2	0?	*Eu*	3972.13	50	50
4129.87	4	1	*Eu*	4129.88	100	100
4205.21	6	1	*Eu*	4205.19	100	50
4435.53	2	5 *Ca* 4 *Ca*	Possibly *Eu* 4435.7	.....	.....	.....

A. Belopolsky. The intensities of the lines in the laboratory and the wave-lengths in the laboratory and star are given in Table II. The wave-lengths are in the old Rowland system. The lines λ 4129 and λ 4205 had been shown by Belopolsky[3] to vary periodically in intensity, in phase, in a period of about 5.5 days. An examination by Baxandall of spectrograms obtained at South Kensington of Sirius, α Cygni, and Procyon presented varying degrees of probability of the occurrence of europium in these stars. His results are given in Table III. The wave-lengths are in the Rowland system.

[1] *Philosophical Transactions of the Royal Society of London*, A, **206**, 403, 1906.

[2] *Observatory*, **36**, 440, 1913, and *Monthly Notices of the Royal Astronomical Society*, **74**, 32, 1913.

[3] *Astronomische Nachrichten*, **196**, 1, 1913; also *Bulletin de l'Académie Imp. des Sciences de St. Petersbourg* (6th ser.), **7**, 689, 1913.

From the foregoing evidence Baxandall concluded that the occurrence of europium in α Canis Majoris was established. He considered the evidence unconvincing in the case of α Cygni, and inconclusive

TABLE II

EUROPIUM IN α^2 CANUM VENATICORUM (BAXANDALL)

λ (ROWLAND)	LABORATORY (E. AND H.)			
	Intensity		α^2 CVn (Belopolsky) λ (Rowland)	Remarks
	Spark	Arc		
3930.65.....	50	50	3930.67	
3972.16.....	50	50	.....	Masked by $H\epsilon$ in star
4129.90.....	100	100	4130.04	
4205.20.....	50	100	4205.20	
4435.75.....	30	50	4435.77	Stellar line partly due to *Ca* 4435.85
4522.76.....	15	20	4522.87	Stellar line probably chiefly due to p*Fe* line 4522.80
4594.22.....	10	100	4594.26	

TABLE III

EVIDENCE FOR OCCURRENCE OF EUROPIUM IN A AND F STARS (BAXANDALL)

LABORATORY (E.–H.)	α CMA		α CYG		α CMI	
λ (Rowland)	λ (Rowland)	Notes	λ (Rowland)	Notes	λ (Rowland)	Notes
3930.65.....	3930.52	Probably blend of *Eu-Fe*	3930.52	Possibly blend of *Eu-Fe*	.....	Masked by *Ca* K
3972.16.....	.....	Masked by $H\epsilon$	.....	No evidence for stellar line	.....	Masked by *Ca* H and $H\epsilon$
4129.90.....	4129.91	Faint, probably *Eu* only	.....	No evidence for stellar line	4129.6	Weak stellar line apparently more refrangible than *Eu* line
4205.20.....	4205.21	Faint, probably *Eu* only	4205.2	Possibly blend of *Eu*-p*V*	4205.10	Possibly *Eu* only
4435.70.....	.....	Doubtful in stellar spectrum	.....	No evidence for stellar line	4435.9	Probably chiefly *Ca;* possibly *Eu* also
4522.70.....	4522.7	Chiefly p*Fe* 4522.80, but possibly a a blend with *Eu*	4522.7	Strong stellar line, chiefly p*Fe;* possibly blend of *Eu*-p*Fe*	4522.9	Probably chiefly p*Fe;* possibly *Eu* also
4594.22.....	4594.18	Stellar line probably *Eu*	4594.42	Possibly *Eu*	4594.3	Possibly *Eu* only; evidence for *V* 4594.27 weak

for α Canis Minoris. He also compared the strongest europium lines with the solar spectrum.

S. A. Mitchell[1] attributed six lines in the flash spectrum as observed at the eclipse of 1905 to europium. In a later paper[2] a catalogue of lines is given, determined principally from the chromospheric spectra of 1905 and 1925. In this paper four lines are ascribed to Eu^+. The wave-lengths in the chromosphere together with other data are given in Table IV. The wave-lengths are in I.A.

TABLE IV

OCCURRENCE OF Eu^+ IN THE CHROMOSPHERE (MITCHELL)

λ (I.A.) CHROMOSPHERE	λ (I.A.) SUN	ELEMENT	INTENSITY		HEIGHT IN KM
			Disk	Flash	
3906.99.....	3906.96	Eu^+	1	2	600
3971.89.....	3971.91	Eu^+-Fe	1	3	700
4129.73.....	4129.73	Eu^+	1	10	600
4205.06.....	4205.06	V^+-Eu^+	2	6	600

It seems that the wrong solar line was identified with the europium line at λ 3907. From a more exact determination of the wave-length of the Eu^+ line by A. S. King identification with another solar line is indicated (see Table VII).

In an extension of the work of Ludendorff, of Belopolsky, and of Baxandall on the spectrum of α^2 Canum Venaticorum, C. C. Kiess[3] identified several other lines with europium among those found to vary in intensity. Table V gives all of the lines which he considered to be due to europium. The wave-lengths are on the old Rowland system.

Miss Cecilia Payne[4] suggested the identification of two lines measured by Lockyer and Baxandall in the spectrum of γ Cygni with the two strongest lines of europium. She also identified two weak lines in the solar spectrum as being identical with the same europium lines. As Adams and Joy have pointed out,[5] however, it seems that

[1] *Astrophysical Journal*, **38**, 407, 1913.

[2] *Ibid.*, **71**, 1, 1930.

[3] *Publications of the Observatory, University of Michigan*, **3**, 106, 1919.

[4] *Harvard Bulletin*, No. 841, 2, 1926.

[5] *Proceedings of the National Academy of Sciences*, **13**, 393, 1927.

the wrong lines were identified with europium by Miss Payne in the solar spectrum. Adams and Joy have published wave-lengths determined for the two strongest europium lines from large-scale spectrograms of γ Cygni taken with the coudé spectrograph of the Mount Wilson Observatory. Their measures are included in Table VI. The wave-lengths are expressed in I.A.

TABLE V

EUROPIUM LINES IN α^2 CANUM VENATICORUM (KIESS)

λ (ROWLAND) Star	λ (ROWLAND) Laboratory
3820.0	*Eu* 3819.80
3899.1	(*Eu* 3898.90)
3907.3	*Eu* 3907.29
3930.6	*Eu* 3930.66
3972.0	*Eu* 3972.16
3978.6	(*Eu* 3978.60)
4085.8	(*Eu* 4085.54)
4129.7	*Eu* 4129.90
4205.3	*Eu* 4205.20
4435.4	*Eu* 4435.75
4522.8	*Eu* 4522.76
4912.5	*Eu* 4912.61

TABLE VI

EUROPIUM LINES IN γ CYGNI (ADAMS AND JOY)

λ Lab. (I.A.)	λ Sun (I.A.)	λγ Cyg. (I.A.)
4129.72	4129.73	4129.72
4205.03	4205.03 4205.08 V^+	4205.06

D. H. Menzel[1] has called attention to the remarkable behavior of the lines due to the rare earths on a moving plate spectrogram taken at the eclipse of 1905 by W. W. Campbell. Instead of reversing to dark lines at the limb of the sun they remained in emission far in on to the disk of the sun.

The recent determination of accurate wave-lengths of the strongest europium lines and the temperature classification of all the lines, by King,[2] have made it seem desirable to try to obtain more data as

[1] *Publications of the Astronomical Society of the Pacific*, **39**, 359, 1927.

[2] *Astrophysical Journal*, **72**, 221, 1930.

to the occurrence and behavior of the element in the stars. Table VII gives the wave-lengths and intensities in the furnace and arc of all of the europium lines having intensities of 30 or greater. The wave-lengths to two places are by Eder;[1] the more accurate ones were measured by King. The lines which occur in the sun are also listed. The wave-lengths, identifications, and intensities in the sun

TABLE VII

INTENSITIES, WAVE-LENGTHS, AND TEMPERATURE CLASSIFICATION OF STRONGEST EUROPIUM LINES (A. S. KING) WITH OCCURRENCE IN THE SUN

λ (I.A.)	Intensities		Class; No. Comps.	λ Sun	Iden.	Int. Disk	Int. Spot
	Arc	Fur.					
3884.76	50	8	III, 3				
3907.113	300R	30	III E, 4	3907.116		0Nd?	
3917.30	30	5	III, 3				
3930.425	15?	2?	III E				
3930.504	300R	50	III E, 3	3930.515	Eu^+?	0	
3971.899	20?	3	III E				
3971.989	400R	60	III E, 3	3971.996	Eu^+?−	0d?	0
4039.20	30	12	III, 2				
4129.639	25?	4?	III E				
4129.734	500R	80	III E, 3	4129.732	Eu^+	1	1
4204.909	30?	5?	III E	(4204.897)		−2	
4205.046	600R	100	III E, 3	4205.029	Eu^+?	1	2*
4298.73	30	4?	III				
4355.10	30		V E				
4435.473	20?	10	III E				
4435.602	400r	80	III E, 3	Masked by *Ca* 4435.690			
4522.602	200r	50	III E, 4	Masked by Fe^+ 4522.640			
4593.993	500R	200R	II				
4627.122	300R	150R	II				
4661.865	250R	100R	II				

* Blended with V^+ in spot spectrum.

were taken from the *Mount Wilson Revision of Rowland's Preliminary Table of Wave-Lengths.*

King describes the strongest lines in the spectrum as follows:

The lines of low excitation in the ionized spectrum have intensities seldom found in rare-earth spectra. These are λλ 3907.1, 3930.5, 3971.9, 4129.7, 4205.0, 4435.6, 4522.6. The line λ 3819.6, outside the range here studied, belongs to the group. In structure each line consists of an unresolved triplet, with a fourth

[1] *Sitzungsberichte der Akademie der Wissenschaften in Wien*, IIa, **126**, 473, 1917.

line, usually separated in the furnace spectrum, on the violet side. . . . . The ionized character of these lines was clearly shown by their almost complete extinction when caesium was added in the furnace; but with europium alone the lines are strong in the furnace, and with long exposures show at temperatures as low as 2000° C. . . . .

The neutral lines of europium present a similar contrast between groups. Three low-temperature lines occur at λλ 4593.993, 4627.122, 4661.865. . . . .

As the europium lines seemed to reach their greatest intensity in α^2 Canum Venaticorum whose spectral type is Aop, it seemed that a search through the large collection of spectrograms of A-type stars obtained at the Yerkes Observatory might bring to light other "europium stars." The stars examined cover a range of spectrum Ao–A3 inclusive. The number of stars examined in each spectral subdivision is given in Table VIII. It should be pointed out that the broad, hazy lines in many A-type stars caused by rapid rotation prevent the observation of comparatively weak lines such as the europium ones. For this reason stars whose spectral lines are of poor quality were omitted from the discussion.

TABLE VIII

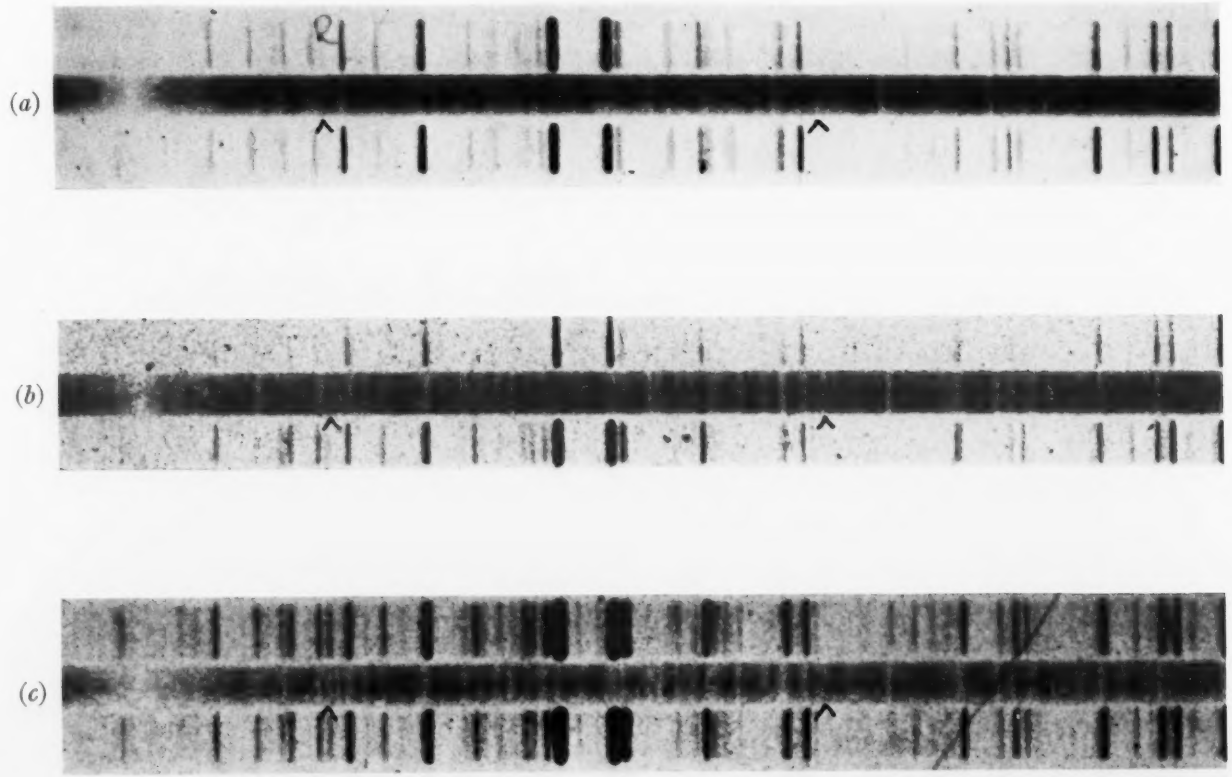
NUMBER OF A STARS EXAMINED FOR EUROPIUM

Sp.	No. Stars
Ao	200
A2	110
A3	50

The total number of stars examined on Yerkes spectrograms is therefore 360. Of this number 34 were found whose spectrum contained a line at λ 4205 agreeing in position with the strongest line of Eu^+. Of these, 13 showed lines at both λ 4129 and λ 4205. The number of stars mentioned includes α^2 Canum Venaticorum, α Canis Majoris, and α Cygni, which had been previously found by Baxandall. One of the stars found, B.D. −18°3789, proved to have a spectrum of unusual interest and has formed the subject of a separate paper.[1] The four strongest europium lines in its spectrum were found to vary in intensity in a probable period of 3.2 days. The chromium lines in the spectrum are also variable in intensity in the same period, but chromium attains its maximum intensity at the time when the europium lines are at a minimum.

[1] *Astrophysical Journal*, **74**, 24, 1931.

PLATE VII



Spectra of (*a*) 78 Virginis, (*b*) 16 Orionis, and (*c*) −19°4135 Librae in the region λλ 4090–4270. The wave-lengths increase toward the right. The Eu^{+} lines at λλ 4129 and 4205 are marked.

Table IX lists the stars found to have lines corresponding in position to one or more of the strongest europium lines.

The intensities of a selected group of lines were estimated on two plates for each star. The wave-length of the line at λ 4205 was de-

TABLE IX

A-STARS CONTAINING LINES CORRESPONDING IN POSITION WITH STRONGEST EUROPIUM LINES

Star	α (1900)	δ (1900)	Vis. Mag.	Spectrum
5 γ Ari (S)	1^h48^m	+18° 48′	4.83	Aop
+70°257 Cam	3 39	+70 34	5.40	Ao
+25°624 Tau	3 44	+25 17	5.38	A3
68 Tau	4 20	+17 42	4.24	A2
4 Cam	4 40	+56 35	5.35	A2
+11°646 Ori	4 40	+11 31	5.43	Ao
16 Ori	5 04	+ 9 42	5.42	A2
14 Aur	5 09	+32 34	5.14	A2
27 ο Aur	5 38	+49 47	5.52	Ao
40 Aur	6 00	+38 29	5.31	A3
9 α CMa	6 41	−16 35	−1.6	Ao
66 α Gem (ft)	7 28	+32 06	2.85	Ao
2 UMa	8 26	+65 29	5 39	Ao
49 Cnc	8 39	+10 27	5.58	Aop
65 α Cnc	8 53	+12 15	4.27	A3
67 UMa	11 57	+43 36	5.07	A3
17 Com	12 24	+26 28	5.38	Aop
77 ε UMa	12 50	+56 30	1.68	Aop
12 α^2 CVn	12 51	+38 51	2.90	Aop
78 Vir	13 29	+ 4 10	4.93	A2p
−18°3789 Vir	14 13	−18 15	5.74	Aop
7 μ Lib	14 44	−13 44	5.38	A2p
−19°4135 Lib	15 27	−19 20	5.46	A2
+55°1779 Dra	15 45	+55 41	5.79	A2
37 ε Ser	15 46	+ 4 47	3.75	A2
52 Her	16 46	+46 10	4.86	A2p
+25°3246 Her	17 16	+25 38	5.32	A2
6 ζ Lyr (br)	18 41	+37 30	4.29	A3
10 Aql	18 54	+13 46	5.94	A3p
58 π Dra	19 20	+65 31	4.63	A2
73 Dra	20 33	+74 37	5.18	A2p
50 α Cyg	20 38	+44 55	1.33	A2p
+48°3390 Cyg	21 23	+48 24	5.31	A3
32 Aqr	22 00	− 1 23	5.23	A3

termined for all of the stars, and the line at λ 4129 was measured in the thirteen cases where it was found to be present. These results are given in Table X. The columns give: (1) the name of the star and the spectral type; (2) the estimates of intensity of twenty-one lines, including those at the position of the europium lines; and (3)

the measured wave-lengths for λ 4129 and λ 4205, and their deviations from the laboratory positions.

As Yerkes one-prism plates are generally weak to the violet of λ 4000, it was thought best to observe lines which are situated to the red of this position. This reduced the number of strong ionized europium lines to four in the observable range. These were λλ 4129, 4205, 4435, and 4522. Of these, the last two may be seriously blended. There is a strong neutral calcium doublet at λ 4435, which is present in the cooler A stars. The line at λ 4522 is hopelessly blended with the Fe^+ line at the same position. There is a moderately strong V^+ line at λ 4205.082 in the sun. As the strongest Eu^+ line lies at λ 4205.046 the presence or absence of V^+ was determined from other, stronger vanadium lines. Table XI gives the strongest lines of ionized vanadium in the region observed.

TABLE X

	Star	Sp.	V^+ 4023	Si^+ 4128	4130	Si^+ 4131	4132	Fe 4202	4205	Sr^+ 4215	Ca-Fe 4227	Fe^+ 4233
1	γ Ari (S)	Aop	0	2–3	0	1	2	1	1–2	1–2	1	3–4
2	70°257 Cam	Ao	0	1–2	0	1	1–2	1–2	1–2	4–5	2	3–4
3	25°624 Tau	A3	0	1	0	0	1	1	1	1	1	0
4	68 Tau	A2	0	2–3	0	1–2	2–3	2	1	2–3	1	3
5	4 Cam	A2	0	2	1	0	1	2	2	2–3	2–3	2–3
6	+11°646 Ori	Ao	0	2	0	1	1	2–3	1	2–3	3	2–3
7	16 Ori	A2	0	3	1	2	3	2–3	2–3	4–5	3	3–4
8	14 Aur	A2	0	1–2	0	1	2	2	1	3–4	3–4	3–4
9	ο Aur	Ao	0	1	0	0	2	1	1	1	1–2	2
10	40 Aur	A3	0	2–3	0	1	3	3	3	5	3–4	4
11	α CMa	Ao	1	4	1	4	2–3	2–3	1	3–4	2	5
12	α Gem (ft)	Ao	1:	2	0	2	2	3	1	3–4	3	3
13	2 UMa	Ao	0	2	1	1	2	2	1–2	4–5	2	3
14	49 Cnc	Aop	0	3–4	0	3–4	1–2	1?	1–2	2–3	1	2–3
15	α Cnc	A3	0	1–2	0	1?	1–2	1–2	1	2–3	2–3	3
16	67 UMa	A3	0	1–2	0	0	1	1–2	1	3	2	2
17	17 Com	Aop	0	2	0	1	2	1	2	2–3	1	3
18	ε UMa	Aop	1	3–4	0	2	4	2	2	4	2–3	5–6
19	α^2 CVn (max)	Aop	0	4–5	3	4–5	3–4	0	4–5	2	2–3	3
20	α^2 CVn (min)	.....	.....	5	0	5–6	1–2	0	1–2	2	1	4–5
21	78 Vir	A2p	0	1–2	2	1	3–4	1	2–3	4	1	3–4
22	−18°3789 Vir (max)	Aop	0	2	2	1	3	0	4–5	1	2	2
23	−18°3789 Vir (min)	.....	0	2	1	1	3	1	2	3	2	5
24	μ Lib	A2p	0	1	1	1	2	1	1	6	1–2	2–3
25	−19°4135 Lib	A2	0	3	1–2	2–3	3	3	2	3–4	3–4	3–4
26	55°1779 Dra	A2	0	3	0	1	3	3	1–2	3–4	3	3–4
27	ε Ser	A2	1	3	0	3	3–4	4	1–2	6	4	6
28	52 Her	A2p	0	1–2	1	1	2–3	1–2	1–2	4–5	1–2	3
29	25°3246 Her	A2	1	2	0	1–2	1	2	1	4	2–3	4
30	ζ Lyr (br)	A3	2	3	1	2	3	3	3	4–5	4	4
31	10 Aql	A3p	0	2	2	1	2	2	1–2	5	4	3
32	π Dra	A2	0	1–2	0	1	1	1	1	3	1–2	2–3
33	73 Dra	A2p	0	1	2	1	2–3	1	2	5	1–2	3–4
34	α Cyg	A2p	1	6	0	5	1	1	1	1–2	1	8
35	48°3390 Cyg	A3	0	2–3	0	2	2–3	1–2	1–2	4	3	4
36	32 Aqr	A3	0	1–2	1	1	2–3	2–3	1–2	3–4	2–3	3–4

TABLE X—*Continued*

	4435	Mg^+ 4481	Ti^+ 4501	Fe^+ 4508	Fe^+ 4522	Fe^+-Ti^+ 4549	Cr^+ 4558	Ti^+ 4563	Ti^+ 4572	Meas. 4205	Lab.—Star	Meas. 4129	Lab.—Star
1	0	3–4	1	1	1	3	2–3	1	1	4205.16	−11	.....	.....
2	0	4–5	2	1	1–2	3	1	1	1	4204.92	+13	.....	.....
3	0	1	1	0	1	1	0	1	1	4205.18	−13	.....	.....
4	0	5	1	1	1–2	3–4	1	1	1–2	4205.18	−13	.....	.....
5	0	4–5	1	1	1	3	1	1	1	4204.99	+ 6	4129.67	+ 7
6	0	4	1–2	1–2	1	3–4	1	1	1	4205.09	− 4	.....	.....
7	1	4	2	1–2	2–3	4	1–2	1	2	4205.01	+ 4	4129.80	− 7
8	1	4	1–2	1	1–2	3–4	1–2	1	2	4205.11	− 6	.....	.....
9	0	2	1	0	0	1	1	1	1	4205.20	−15	.....	.....
10	1	4	2	1	2	4	1	1	2	4205.15	−10	.....	.....
11	0	8	2–3	2–3	3	5	2–3	2–3	3	4205.08	− 3	4129.69	+ 4
12	0	4	2	1	1–2	3–4	1	1	2	4205.07	− 2	.....	.....
13	0	4–5	2	1	2	3–4	1	1	2	4205.10	− 5	4129.55	+18
14	0	4	2	1	1	4	2	1	1–2	4205.10	− 5	.....	.....
15	0	4	1–2	2	1–2	3	1	1	2	4204.98	+ 7	.....	.....
16	0	4	1	1	1	3	1	1	1	4205.08	− 3	.....	.....
17	1?	5	1–2	0	1	3–4	3–4	1	1	4205.14	− 9	.....	.....
18	0	6–7	2	2	2	5–6	4	1	1–2	4205.08	− 3	.....	.....
19	2	4–5	1–2	1	2–3	4–5	2	1–2	2–3	.....	.....	.....	.....
20	0	4–5	1	1	2	4	2–3	0	1	.....	.....	.....	.....
21	1?	4	1	1	1	3–4	3	1	1	4205.10	− 5	4129.85	−12
22	2	2–3	1	1?	3	4	1	1	1–2	4205.07	− 2	4129.91	−18
23	0	4	1	1?	2	4–5	4	1	1	.....	.....	.....	.....
24	0	5	1	1?	1	3	3	1	1	4205.20	−15	4129.52	+21
25	1?	5	2	2	2–3	4–5	1–2	1	2	4205.14	− 9	4129.57	+16
26	0	4–5	2	1–2	2–3	4	1	1	2–3	4204.94	+11	.....	.....
27	1	6	3	3	3	5	3	2–3	3	4204.96	+ 9	.....	.....
28	1	4	1	1	1	3–4	1–2	1	1	4205.02	+ 3	4129.60	+13
29	1:	5–6	1–2	1–2	1–2	4	1–2	1	1	4205.25	−20	.....	.....
30	1	5	2	2–3	2–3	4	2	2	2–3	4204.92	+13	4129.75	− 2
31	2	5	1	1	1	2	1	1	1	4204.81	+24	4129.62	+11
32	0	5	1–2	1–2	1	3	1–2	1	1–2	4204.98	+ 7	.....	.....
33	0	5	2	1	1	3–4	4	1	1	4204.88	+17	4129.75	− 2
34	0	8	3–4	5	5	6–7	5	2–3	3–4	4204.99	+ 6	.....	.....
35	0	5	2	1	1–2	4	1–2	1	1	4205.21	−16	.....	.....
36	1	3	2	1–2	1–2	4	2	1–2	2–3	4205.01	+ 4	4129.53	+20

TABLE XI

STRONGEST LINES OF V^+ IN REGION OF STELLAR SPECTROGRAMS

λ	Int. (Lab.)	Int. Disk	Int. Spot	Iden.	E.P.
4005.712.....	60	3	1	V^+	1.809
4023.376.....	50	3	2	V^+-Co	1.797
4035.622.....	40	2	1	V^+	1.785
4183.428.....	35	2N	1	V^+—	2.041
4202.34.....	35	0Nd?	0	V^+	1.696
4205.087.....	30	1	*	V^+	1.678 2.027

* V^+ 4205.087 is blended with Eu^+ 4205.046 in sun-spot spectrum. The blend is given by Rowland as intensity 2.

The only one of the three strongest lines that is unblended in A-type stars is λ 4023. The intensity of this line was therefore esti-

mated on all of the plates. If λ 4023 was found to be absent, it seemed safe to conclude that V^+ can make no sensible contribution to the stellar line at λ 4205.

The strong Eu^+ line at λ 4129 seems to be entirely unblended in A-type stars.

It thus seems that a rather definite decision can be reached concerning the presence or absence of Eu^+ from the evidence of the two strongest lines of the element at λ 4129 and λ 4205.

For two of the stars in Table X there is evidence of another sort. The variation in intensity of these lines in α^2 Canum Venaticorum and in B.D.$-18°3789$, together with the agreement in wave-length, makes the evidence overwhelming. In the case of $-18°3789$ there is no calcium line at λ 4435, and the europium line at that position varies in phase with λ 4129 and λ 4205. The spectra of the rest of the europium stars were examined for possible variability of the spectral lines. In a few cases where a number of plates was available the evidence was negative, but in most instances the data were not sufficient to make a final decision. It is possible that λ 4205 varies in intensity in 73 Draconis.

It seems that the identification with europium is certain in the case of all of the stars in Table X which contain both λ 4129 and λ 4205 and which do not contain vanadium. In only two cases where λ 4129 and λ 4205 occur is the line V^+ 4023 present. In Sirius λ 4023 is equal in intensity to λ 4205. The evidence for the presence of Eu^+ would be unconvincing were it not for the fact that there is a very faint line agreeing in position with Eu^+ 4129. Because of the coincidences of the two lines it seems probable that europium is present in Sirius. In ζ Lyrae, λ 4205 is a rather strong line, while V^+ 4023 is certainly weaker. λ 4129 is stronger than in α Canis Majoris, and it seems practically certain that Eu^+ is present. For the other twelve stars containing both λ 4129 and λ 4205, the identification with europium seems certain since vanadium is absent.

In the case of the stars in which only λ 4205 seems to be present, the evidence cannot be as conclusive. Several stars can be at once eliminated. α Cygni, the only supergiant in Table X, clearly does not contain europium, since the line at λ 4205 is weaker than V^+ 4023, and is thus probably entirely due to vanadium. In B.D.$+25°3246$

Herculis the two lines are about equal in intensity, and it seems probable that λ 4205 can be again explained by the presence of vanadium. In ε Serpentis, λ 4205 is possibly slightly stronger than V^+ 4023. It is impossible to decide with certainty, but it seems probable that europium is not present. The same reasoning applies to α Geminorum. In the case of ε Ursae Majoris, the only other star found to contain V^+ 4023, λ 4205 seems to be definitely stronger than the vanadium line. For this reason it seems that the star can be classed with the last group: those which show λ 4205, but in which both λ 4129 and λ 4023 are absent. Of this group all that can be said is: (1) The line at λ 4205 agrees within the errors of measurement with the strongest line of Eu^+. (2) The presence of the line cannot be accounted for by any other element but europium. (3) The A stars containing λ 4205 form a related group in temperature and pressure. (4) The stars containing λ 4205 alone have spectra similar to those containing both λ 4129 and λ 4205. (5) The ratio of intensity 4129/4205 is such that, except in one case, the faintness of λ 4205 would preclude the probability of seeing λ 4129. The single exception to this rule is 40 Aurigae, in which λ 4205 is of intensity 3, while λ 4129 seems to be absent. It seems that this may possibly be accounted for by the fact that the star is a spectroscopic binary with double lines, and estimates were possible only on the one plate which showed single lines. In connection with (3), estimates of the widths of Hγ and Hδ were made to afford some idea of the range in pressure among the stars. The progressive broadening of the hydrogen lines with increasing pressure, due to Stark effect, serves as a valuable criterion of absolute magnitude. Because of the varying density of the plates, only a rough estimate was possible, but this was sufficient to show that the stars are all of the same order of absolute magnitude. On the scale adopted, the *H* lines in Sirius are of width 7, while those in α Cygni were estimated 1. All of the stars believed to contain europium had estimates for line-width varying from 3–4 to 6 with the exception of ζ Lyrae, which was classed 3. This definitely excludes all supergiants and makes it seem probable that the europium stars are similar to other A-type stars in general as far as pressure is concerned. It is possible that the dispersion would be much less if plates of comparable density were available.

It thus seems fairly certain that Eu^+ is present in the thirteen stars listed in Table X which show the two strongest europium lines, and highly probable for the seventeen others in which the intensity of λ 4205 cannot be accounted for by vanadium.

A rather striking similarity was observed between the behavior of chromium and europium. Every star in the range Ao–A3 in which the lines of ionized chromium are strong was found to contain either one or both of the strongest lines identified with europium. In the case of B.D.−18°3789 it has been shown that the chromium lines are variable in intensity in phase opposite to that of the europium lines. The estimates of intensity of the strongest Cr^+ line at λ 4558 is given in Table X. In such stars as 17 Comae, 78 Virginis, μ Librae, and 73 Draconis, it is equal in intensity to the outstanding Fe^+-Ti^+ 4549, and it is well marked in the majority of the stars. If the equality of *Ca-Fe* 4227 with Fe^+-Cr^+ 4233 be taken as a criterion for spectral class A2, then all of the A stars suspected of containing europium lie within the narrow range Ao–A2.

The mean of the thirty determinations of wave-length of λ 4205 in the stars is 4205.057 A, with a probable error of ±0.012 A, while the laboratory value is 4205.046 A. The mean of the thirteen measures of λ 4129 is 4129.69 A, with a probable error of ±0.024 A, while the laboratory wave-length is 4129.73. The agreement is as good as can be expected. The silicon doublet λ 4128 and λ 4131 was used for the determination of the wave-length of λ 4129, while the following lines were used in the case of λ 4205: Fe^+ 4179, *Fe* 4202, Sr^+ 4215, and Fe^+-Cr^+ 4233.

The ionization potential of europium is not known, but from analogy to the other rare earths it seems rather safe to say that it lies between 6 and 7 volts. The intensity of the europium lines in A-type stars is thus even harder to understand, as the maximum intensity of the first stage of ionization should be much lower in the temperature scale. It is of some interest to note that the europium stars occur immediately below the "manganese"[1] stars in effective excita-

[1] In my study of the "manganese" stars (*Astrophysical Journal*, **73**, 104, 1931) the stage of ionization was found to be probably the second (Mn^{++}). Professor H. N. Russell has suggested that the lines probably arise from the singly ionized atom (Mn^+).

tion. The manganese stars are found among spectral classes B8, B9, and the high-temperature A0 stars. The A-type europium stars occur in the low-temperature A0 stars and in A2 and A3. It seems that since the segregation of these two groups of stars it should be possible to take another step toward the physical classification of the A-type stars.

YERKES OBSERVATORY
WILLIAMS BAY, WIS.
August 25, 1931

A NOTE ON THE MASS OF 27 CANIS MAJORIS

By DEAN B. McLAUGHLIN

ABSTRACT

It is shown that in range of velocity, length of period, correlation of emission and velocity changes, and in the presence of a secondary oscillation of short-period and smaller range than the main period, 27 Canis Majoris is a normal Be spectrum variable. Large variations in the periods of stars of this type rule out the hypothesis of orbital motion, and with it the enormous mass function derived by Struve. The supposed secondary spectrum is also a normal phenomenon of Be variables, and is due to a wing of the broad absorption which underlies and borders the emission lines.

In the *Astrophysical Journal*, Dr. Otto Struve[1] has presented the most recent results of a spectrographic study of 27 Canis Majoris and has derived a mass function of 275 ⊙, making the mass of the system of the order of 2000 ⊙. The order of length of the period (2000 days) would appear to be established beyond question, and the large range of velocity (240 km) is such as to indicate orbital motion as the explanation. The contention that the enormous mass is real seems to be strengthened by the presence of a secondary spectrum which has been measured on many plates[2] and which therefore cannot be disregarded.

It appears to the writer that the explanation of the anomalies of this star is to be found in the fact that it is a spectrum variable of class Be. J. S. Plaskett[3] has shown that the large mass derived by H. Ludendorff[4] in the case of 46 υ Sagittarii is illusory. The present case, though different in its details, is probably of a somewhat similar nature.

Rather large ranges of velocity and long periods are common among the spectrum variables of Class Be. The writer cannot match Struve's mass function, but he has investigated the spectrum of π Aquarii which shows a range of velocity of about 120 km and a

[1] *Op. cit.*, **73**, 301, 1931.

[2] *Ibid.*, **65**, 273, 1927.

[3] *Publications of the Dominion Astrophysical Observatory*, **4**, No. 1, 1927.

[4] *Sitzungsberichte der preussischen Akademie der Wissenschaften*, **9**, 67, 1924.

period of 1900 days in the interval 1924–1930.[1] These figures lead to a mass function of more than 30 ⊙. But the period just stated is not rigorously adhered to, and there are some indications that the large range of velocity is a recent development. The case of 25 Orionis, while yielding a much smaller mass function, is more conclusive as regards non-constancy of period. R. H. Curtiss[2] found for this star a mean period of 1890 days during the interval 1915–1928. The writer has confirmed this period for the earlier observations, but recently one cycle of variation occupied only about 1300 days. While these periods are based chiefly upon the variation of the ratio of violet to red emission components, they are also valid for the variation of velocity, since the writer[3] has shown that the curves of the ratio of emission are almost identical in form with the velocity-curves. With such irregularity in the lengths of cycles we must certainly abandon the hypothesis of orbital motion in these cases. It is thus an easy step to the conclusion that the variation of velocity of 27 Canis Majoris does not represent orbital motion, since it also is a Be spectrum variable and behaves in a perfectly normal fashion for such a star, viz., in showing greater strength of the red emission component when the velocity is negative and greater strength of the violet component when the velocity is positive.

A further point of similarity between this star and others of the same type is found in the existence of a shorter period of the order of 100 days, with a smaller range of velocity than that of the long-period variation. Such a situation is highly improbable in a true multiple system. Such a short period is definitely indicated in π Aquarii and suspected in 25 Orionis, while in ζ Tauri[4] the short period was known before the long one was detected. Thus, in several respects 27 Canis Majoris is a typical Be spectrum variable—indeed, it appears to differ from other cases only in possessing a larger range of velocity than any other so far investigated. The intensive observations have not been carried on over a long-enough interval of time to show the extent of its irregularities.

[1] *University of Michigan Observatory Publications*, **4**, No. 3, 1931.

[2] *Popular Astronomy*, **37**, 578, 1929.

[3] *Loc. cit.*

[4] Losh, *University of Michigan Observatory Publications*, **4**, No. 1, 1931.

The secondary spectrum remains to be considered. In this respect also the star is apparently normal for a Be variable. In both π Aquarii and 25 Orionis the writer has seen such "secondary spectra," but in these cases it is quite clear that they are not due to a second body at all. Be stars normally present a narrow absorption line almost centrally placed in a wide emission line, which in turn is superimposed upon a broad absorption. *The emission, with its narrow central absorption, shifts positively when the violet emission component strengthens. The underlying broad absorption does not share this displacement*, hence the wing of shorter wave-length of the broad absorption will be uncovered and the wing of greater wave-length will be almost or quite obliterated by the shifting emission. The uncovered (and hence relatively intensified) wing appears in about the position where a line of the secondary spectrum would be expected to appear. An opposite change occurs when the red emission component is stronger. In the stars studied by the writer both wings can be seen when the emission is in its median position, but there seems to be no good reason why the emission in some star might not be wide enough to cover both wings of the absorption except when a large shift of the emission and its central absorption occurs. The writer suggests this structure as the probable interpretation of the secondary spectrum in 27 Canis Majoris.

The noticeable emission in this star is confined to the hydrogen lines. It is not entirely clear why the helium lines should show the same displacements as the hydrogen, in spite of the absence of observable emission. The quality of the helium lines is such that it is difficult to ascribe their doubling to the cause suggested above in the case of the hydrogen lines. This and other difficulties can only be cleared up by further investigation. The crux of the matter is evidently the question of regularity of period.

Orbital motion, and with it the enormous mass, is ruled out by the foregoing considerations. Pulsation, in the ordinary sense, is likewise impossible as an explanation of the velocity variations of this star—at least a star whose surface pulsates through a distance several times its own diameter is inconceivable to the writer. A modification of C. S. Beals's hypothesis[1] of ejection of the atmospheres of

[1] *Publications of the Dominion Astrophysical Observatory*, 4, No. 17, 1930.

the Wolf-Rayet stars seems to the writer the most hopeful approach to an explanation of the emission and velocity changes of the Be spectrum variables. We should, however, keep in mind the remote possibility that the shifts of lines are not due to real motions of the gases in the line of sight, but are caused by some changes of an unknown nature in the atomic mechanism of absorption and emission of light.

THE OBSERVATORY
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STELLAR ABERRATION AND RED SHIFT

By G. VAN BIESBROECK

ABSTRACT

The position of a distant nebula, which has shown a large recessional velocity, has been measured photographically in order to ascertain if the yearly aberration has the same value for the nebula and for the surrounding stars. No measurable difference was found, showing that the high velocity of the source does not affect the velocity of the light.

The constancy of the velocity of light is a fundamental postulate in the theory of aberration. We have learned to doubt all theories and to examine critically our postulates. This one has not been an exception, and the possibility that the velocity of the source might affect the velocity of the light has been freely mentioned in recent literature. Without going into the delicate treatment of the theoretical problem, I thought it would be of interest to make an experimental test of the constancy of the astronomical aberration for objects showing considerable red shifts in the spectral lines. If considered as Doppler shifts, these would correspond to velocities of thousands of kilometers per second. As a test object I have used a small elliptic nebula—which should better be called a spiral—the brightest one of a remarkable cluster of nebulae found by W. Baade in Ursa Major.[1] This object, No. 24 in Baade's list, where it is called of magnitude 15.93, shows a red shift corresponding to a radial velocity of +11,500 km per second according to M. Humason's determination with the Rayton short-focus spectrograph attached to the 100-inch reflector at Mount Wilson.[2] If the large velocity of recession were combined with that of the light, it would mean a change of +0.78″ in the constant of aberration. The aberrational ellipse would therefore be 1.56 larger for the nebula than for the surrounding stars.

Twelve plates taken with the 24-inch reflector of the Yerkes Observatory were secured during the six months' interval February to August, 1931, so as to cover fully one-half of the aberrational ellipse.

[1] *Astronomische Nachrichten*, **233**, 65, 1928.

[2] *Astrophysical Journal*, **71**, 356, 1930.

The position of the nebula was measured in rectangular co-ordinates relatively to five comparison stars of magnitude 16 to 17. Each measure gave an equation of the form

$$\text{Aberration} \times a + \text{Constant} = \text{Measure},$$

in which a is the fraction of the stellar aberration by which the aberration of the nebula would be greater if its velocity were combined with that of light. If this were the case, a would be

$$\frac{11{,}500}{300{,}000} = +0.038.$$

No term for parallax nor proper motion is included in the equation; the plates cover only an interval of six months, and for such faint objects these quantities are of course entirely negligible.

The solution of the 24 equations, one in x and one in y for each plate, gave

$$a = +.006 \pm .006 \text{ (m.e.)},$$

a value six times smaller, and within the uncertainty of its determination. The mean error of one measure on the nebula comes out $0''.34$, which seems large, but the scale of the plates is $87''$ to the millimeter, and the diffuse nebula, having a size of 13 by $15''$, is none too easy to bisect.

The conclusion is that the red shift found in the spectrum of the most distant nebulae, be it interpreted as Doppler shift or otherwise, has no effect of the first order on the value of the yearly aberration.

The same conclusion has recently been arrived at by G. Strömberg.[1]

WILLIAMS BAY, WISCONSIN
September 3, 1931

[1] *Publications of the Astronomical Society of the Pacific*, **43**, 266, 1931.

REVIEWS

Astronomy. By FOREST RAY MOULTON. New York: Macmillan Co., 1931. 8vo. Pp. xxiii+549; 213 diagrams and photographs. $3.75.

Dr. Moulton's new book is an elementary college course in descriptive astronomy and will doubtless take the place of his *Introduction to Astronomy* which first appeared in 1906 and which has since been reprinted and re-edited a number of times.

The author has given careful consideration to the selection of his material. In this he has been guided by a desire to stimulate in the student an appreciation for clear and logical thinking and at the same time to satisfy his natural curiosity concerning the achievements of science. In his introduction the author expresses the hope that "those who have a taste for coherent thinking will derive keen satisfaction in proceeding from fundamental principles and observational data to some important final conclusion." At the same time he wishes the student to "experience the thrills felt by the original discoverers of the wonders that are described."

There are fourteen chapters, treating the constellations, telescopes, the earth and its motions, time, the solar system and its evolution, the sun, stars and nebulae, and the sidereal system. The subject matter is thoroughly up to date and includes references to many of the latest discoveries. The more advanced reader will derive particular satisfaction from chapter xiv, "The Evolution of the Solar System," which in a large measure rests upon Dr. Moulton's own work. It will be recalled in this connection that in 1899 he proved the Laplacian hypothesis to be untenable—a fact which is now universally accepted. In 1900, in collaboration with the late Professor T. C. Chamberlin, he developed the planetesimal hypothesis. In his *Astronomy* the author gives an outline of this hypothesis and compares it with the encounter theory of A. W. Bickerton and with the tidal theory of J. H. Jeans. The chapter closes with a brief description of the cosmological ideas of W. D. MacMillan, according to which a star may either decrease in mass by radiation, if it happens to be in a comparatively "empty" region of space, or increase in mass, if the

process of sweeping up interstellar matter overbalances the loss by radiation.

Special mention should also be made of chapter xvi, "The Sidereal Structure," which gives a remarkably clear and simple account of the organization and the internal motions of the galactic system. There is an interesting outline of the work of Shapley and of Trumpler. The reader will not fail to appreciate section 375, "On the Dynamics of the Galaxy," which contains a very instructive account of the motions to be expected in our stellar system if certain assumptions are made concerning its structure.

Dr. Moulton's book is not a "handbook" on astronomy, and makes no attempt to cover all of the innumerable problems which interest the specialist. The author aims, rather, to give fewer details and to cover them more explicitly. For example, he includes a fairly complete account of recent work on the companion of Sirius, and discusses its relation to the theory of relativity; he mentions briefly the motion of the perihelion of Mercury and the deflection of light near the limb of the sun; but he does not enter into any discussion of the complicated and, in part, conflicting, work of St. John, Evershed, Burns, and others on the red shift of lines in the solar spectrum. Incidentally, the author's attitude toward such problems as relativity is one of caution: He does not deny the observational evidence, nor does he indiscriminately accept all deductions.

In the opinion of the reviewer it is regrettable that only one chapter of sixty-nine pages has been devoted to the important subject "Stars and Nebulae." Stellar and nebular spectroscopy will doubtless be of increasing importance in the study of the sidereal universe, and a rather thorough discussion of this branch of astrophysics is highly to be desired even in an elementary course.

The illustrations are numerous and well chosen, but the quality of the paper does not always do justice to the exquisite beauty of such nebulae as the one south of ζ Orionis, which has the dark marking "Barnard 33" in its center (Fig. 195). There are two almost identical photographs of the Orion nebula (Figs. 192 and 199). The illustrations of stellar spectra are sometimes placed "violet right" (Figs. 143, 145, 146) and sometimes "violet left" (Figs. 165, 166, 169, 173).

An interesting and novel feature of the book is the inclusion of star maps which cover the whole sky and give all stars down to magnitude 4.0. The boundaries of the constellations are given in conformity with the recently adopted system of the International Astronomical Union.

OTTO STRUVE

Délimitation scientifique des constellations. (*Tables et cartes.*) By E. DELPORTE. Pp. 41+28 charts.

Atlas céleste. By E. DELPORTE. London: Cambridge University Press, 1930; New York: Macmillan Co. Pp. 32+28 charts. 5*s*.

These two volumes differ chiefly in that the former includes detailed lists of the boundaries of the constellations, whereas the *Atlas céleste*, which is the revised form distributed in this country, has, instead, tables giving the positions, magnitudes, and spectral classifications of the stars brighter than magnitude 4.5, as well as lists of the easily seen double stars, variables, nebulae, and clusters included in each map. Otherwise they are practically the same, comprising the Report of Commission III of the International Astronomical Union, 1930.

The report consists essentially of charts showing the boundaries of the constellations as officially approved by the I.A.U. The boundaries are taken along arcs of hour circles and of parallels of declination in such a way that all variables discovered prior to the end of June, 1929, remain in the constellation to which they were originally assigned.

This authoritative delimitation of the constellations satisfies a long-felt need in doing away with the confusion in nomenclature of stars hitherto classed as common to more than one constellation. The *Atlas* is not only invaluable to observatories but should also prove useful to anyone doing telescopic work.

P. C. KEENAN

Photographische Sternkarten. (*Wolf-Palisa Karten.*) Series XI, Nos. 201–10. Edited by J. RHEDEN. Published by the editor, Wien, 1931. 25*s* or 15 Rm.

These ten plates extend the well-known Wolf-Palisa photographic maps to additional regions of the sky. The new fields are widely scattered, except that the declinations covered are within the range $-9°$ to $+44°$.

The maps are accompanied by an index and are uniform in format with the earlier ones of the series.

P. C. KEENAN